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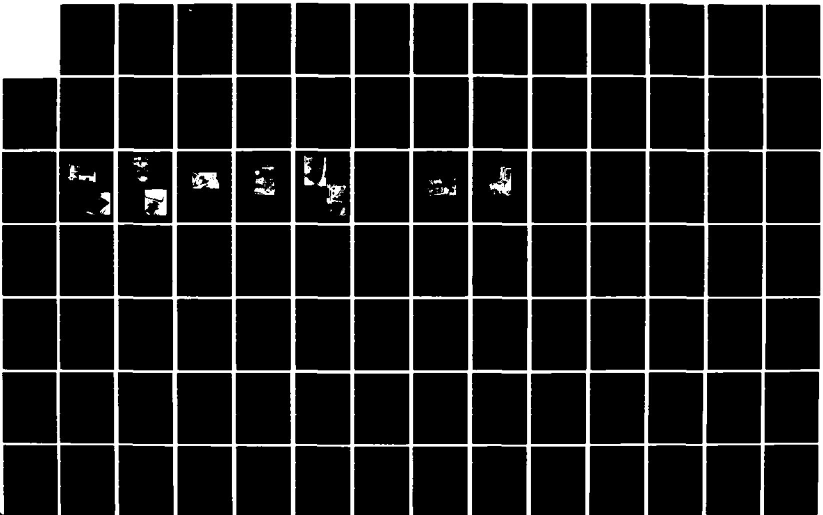

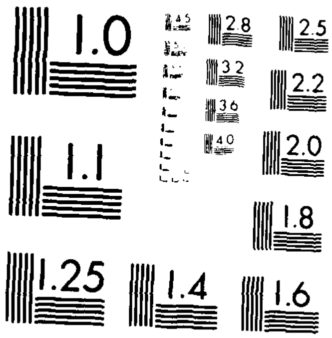
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AD-A152 248

# AN INTERIM REPORT ON THE INVESTIGATION INTO HYDRAULIC GEAR PUMP EFFICIENCIES DURING THE FIRST FEW HOURS OF THE PUMPS' LIVES AND A COMPARATIVE STUDY OF ACCELERATED LIFE TEST METHODS ON HYDRAULIC FLUID POWER GEAR PUMPS

(Parts I And II Of III Parts)

(Part III To Be Published At A Later Date)

BY: The Fluid Power Institute
Milwaukee School of Engineering
November 12, 1979
Under Contract #DAAK70-77-C-0214
to the U.S. Army Mobility Equipment
Research and Development Command,
Fort Belvoir, Virginia

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

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Roll-Off Cleanliness
Traceability
Instrumentation Calibration
NFPA T3.9.17
Measurement Accuracy
Pressure Calibration
Frequency and Time Calibration
Flow Calibration
Torque and Load Cell Calibration
Temperature Calibration

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This interim report summarizes the results obtained in evaluating the changes in overall efficiency of 18 hydraulic gear pumps during the first few hours of the pumps' lives, that is, during the break-in period. A literature search and a mail survey of industry was conducted in order to devise a break-in procedure. Measurement procedures were developed to provide traceability, calibration and verification of the working instruments.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# AN INTERIM REPORT ON THE

# INVESTIGATION INTO HYDRAULIC GEAR PUMP EFFICIENCIES

# DURING THE FIRST FEW HOURS OF THE PUMPS' LIVES

By: The Fluid Power Institute,
Milwaukee School of Engineering
April 27, 1979
Under contract #DAAK70-77-C-0214
to the U.S. Army Mobility Equipment
Research and Development Command,
Fort Belvoir, Virginia

THE FOLLOWING ARE EXTENDED RECOGNITION
FOR THEIR CONTRIBUTIONS TO THIS EFFORT

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Mike Schmidt, Part-time Electronic Technician

Betty Harrison, Department Secretary, Fluid Power Institute

# I. TABLE OF CONTENTS

# II. LIST OF DIAGRAMS AND FIGURES

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| Figure No. | | Page |
|---|---|---|

## III. LIST OF TABULATED AND GRAPHICAL DATA

APPENDIX

## IV. PREFACE

This report is subdivided into parts 1 and 2 in order to lend equal emphasis to both the laboratory program and the program support efforts. Part 1 addresses the laboratory effort and test results. Part 2 details the support work preceding the laboratory program, specifically: development of the laboratory break-in procedure and traceability, calibration, and verification of the measurement system. The appendix contains the data for Part 2.

C. Digital Signal Inputs

2 Channels
Parallel BCD 16 Digits per Channel

D. Calibration

Calibration of the working instruments described in part 2.0 for the most part were conducted using the DAS as the readout device. There were however two exceptions. The frequency counters were individually calibrated prior to use and digitally transferred reading to the DAS. The torque shaft was calibrated using the readout in the signal conditioning amplifier used to excite the torque shaft strain gage bridge. Following calibration, a precision resistor was placed across the bridge and the output recorded. When using the DAS, the signal conditioning amplifier gain was adjusted to obtain the same reading as at calibration time when the precision resistor was again placed across the torque shaft bridge.

1.5.2 Traceability Statements

Pressure - Pressure is traceable to N.B.S. through an Ashcroft dual range dead weight tester type 1305, certificate of accuracy no. 2GH-21398 from Manning, Maxwell and Moore, Inc., Stratford, Conn. dated March 30, 1978. Accuracy is certified to one tenth of one percent.

Volume - Volume is traceable to N.B.S. through Seraphin 5 gallon and 1 gallon test measures, through the Wisconsin Dept. of Agriculture Weights and Measures Laboratory. Wisconsin Test No. 816, dated February 2, 1978.

Temperature - Temperature is traceable to NBS through a Fisher Scientific Thermometer, S/N 673650, through the Wisconsin Dept. of Agriculture Weights and Measures Laboratory. Wisconsin Report No. 816, dated February 2, 1978.

Frequency - Frequency is traceable to NBS thru the ABC Television Network (West coast) and N.B.S. Time and Frequency Bulletin No. 250, September 1978. Accuracy is certified to 3 ppm.

Force - Force is traceable to NBS thru two Lebow load cells, Serial No. 517 and 518. Accuracy is guaranteed to within ± .07% on their certificated dated July 27, 1978.

Length - Length measurements are traceable to N.B.S. thru the Wisconsin Dept. of Agriculture Weights and Measures Laboratory. Wisconsin Report No. 868, dated September 7, 1978.

Flow

2.3 cu. in./rev P.D. Flow meter with 120 tooth gear - magnetic sensor driving a frequency counter

10 cu. in./rev P.D. Flow meter with 80 tooth gear - magnetic sensor driving a frequency counter

Speed

60 tooth gear with magnetic sensor driving a Simpson frequency counter

Frequency Counters

Simpson
Model No. 7016
#1 Flow Rate S/N 03869
#2 Shaft Speed S/N 03874
Parallel DCD Output 10 Digits

Particle Counter

Hiac Model PC 305SSTA S/N 403
Sensor Model D-5-150 S/N 471
Automatic Bottle Sampler

Data Acquisition System

A Monitor Labs, Inc. Model 9300 data acquisition system (DAS) was used for all data collection in the test program. Output from the DAS was transmitted to a teletype which produced a hard copy of the data and punched a paper tape which later was entered into a time-shared computer for data processing. Specifications of the system are as follows:

A. General

Monitor Labs, Inc. DAS
Model 9300
S/N 70
Channel Programmable
Internal Scan Rate 16 Channels/sec
5 Significant Digits

B. Analog Signal Inputs

40 Channels
Voltage Range Fixed + 10VDC
1 $\mu$V sensitivity
Temperature Type J, K, or T Thermocouples
Automatic Reference Junction Compensation

1.5 Test Apparatus

1.5.1 List of Measurement and Support Instrumentation

Information on calibration procedures and error limits for the instrumentation listed below may be found in part 2.0. Detailed calibration data appears in the appendix.

Torque

2000 IN-LB Himmelstein Torque Shaft, 11.6K shunt calibration resistor

Daytronics strain gage indicator Model Number 3278
S/N 1

Daytonics MSOE/N-11741 two channel strain gauge amplifier
Model Number 300D
S/N HF9E1678

Pressure

A. Inlet +/- 5PSID - range

Pace +/- 5 psid pressure transducer M/N KP15
S/N 12752

Pace amplifier M/N CD25
MSOE # 11730

B. Outlet

Viatran 0-5000 psig pressure transducer M/N 218-15
S/N 328176

FPI Power Supply #3

Temperature

A. Inlet

FPI #0 Iron-Constantan thermocouple
FPI #0A Iron-Constantan thermocouple

B. Outlet

FPI #1 Iron-Constantan thermocouple
FPI #1A Iron-Constantan thermocouple
FPI #1B Iron-Constantan thermocouple

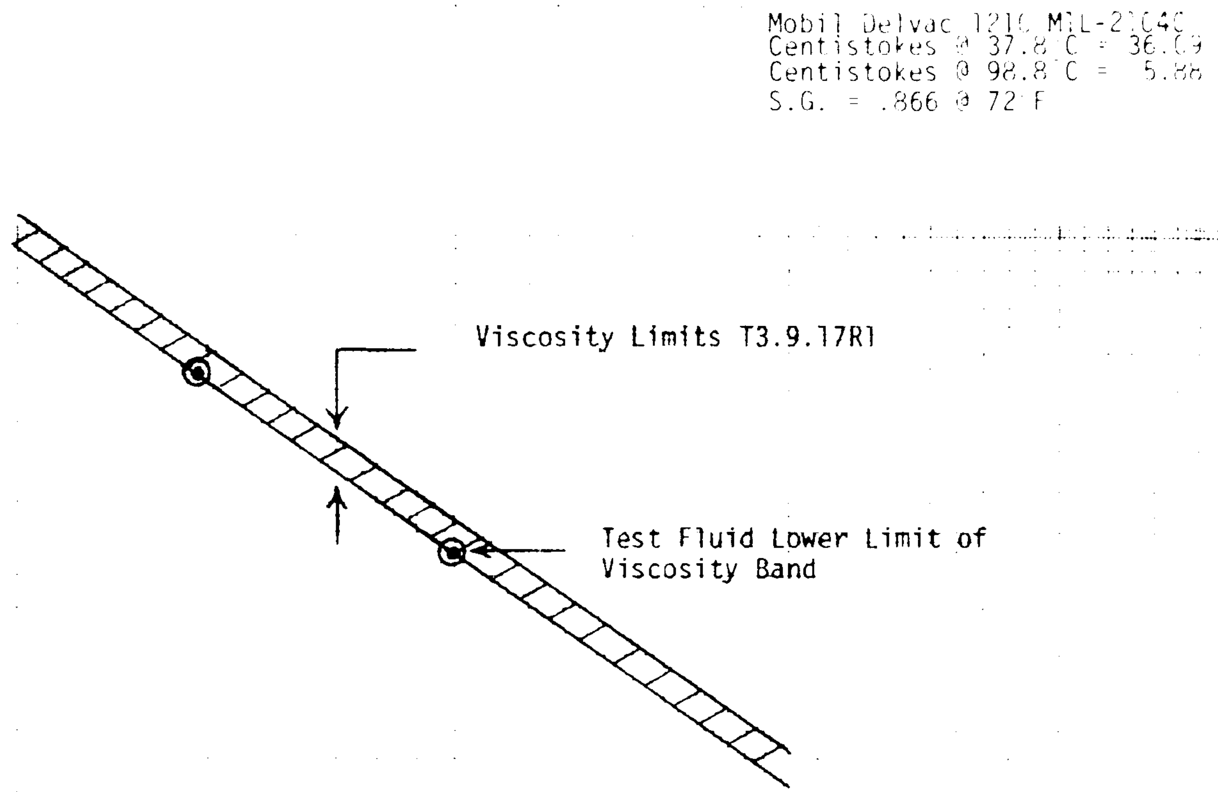

Mobil Delvac 1210 MIL-2104C
Centistokes @ 37.8°C = 36.09
Centistokes @ 98.8°C = 5.88
S.G. = .866 @ 72°F
Viscosity Limits T3.9.17R1
Test Fluid Lower Limit of
Viscosity Band

Figure 1.4.1

TABLE 2 - PARAMETER CONTROL REQUIREMENTS

HYDRAULIC FLUID POWER PUMP TESTS

| PARAMETER CONTROL - CURRENT RECOMMENDATION | | COMPARISON OF PRESSENT INDUSTRIAL STANDARDS | |
|---|---|---|---|
| Parameter Name | Control the Parameter Within the Following Tolerances | NFPA T3.9.17-1971 ANSI B93.27-1973 | SAEJ745C - 1970 |
| Shaft Speed | ± 5% of Rated Speed | ± 2% of * | Not Given |
| Inlet Pressure Below Atmospheric | ± 0.25 in Hg | ± 2% of * | Not Given |
| Inlet Pressure Above Atmospheric | ± 1% of Maximum Measured Inlet Pressure | ± 2% of * | Not Given |
| Inlet Temperature | ± 3.0°C (± 5°F) | ± 2.8°C | Not Given |
| Flow | (Meaningless in a pump test) | ± 2% of * | Not Given |
| Viscosity | (May be inconsistent with temperature) | ± 10% of * | Not Given |

* The identified industrial standard does not specify the method by which the percentage is to be used to calculate the permitted error limit.

TABLE 1 - INSTRUMENT. ION REQUIREMENTS

HYDRAULIC FLUID POWER PUMP TESTS

STRUCTURAL INTEGRITY AND POWER CONVERSION TESTS

| LIMITS OF WORKING INSTRUMENT ERRORS | | | | | COMPARISON OF PRESENT INDUSTRIAL STANDARDS | |
|---|---|---|---|---|---|---|
| Measured Quantity | Letter Symbol | SI Unit | US Unit | Instrument Error as Evaluated in Appendix G shall not exceed this limit | NFPA T3.9.17-1971 ANSI B93.27-1973 | SAEJ745C - 1970 |
| Shaft Speed | $N_I$ | RPM | RPM | ± 0.5% of Rated Speed | ± 5% of * | ± 5% of * |
| Inlet Pressure (Below Atmospheric) | $P_I$ | Bar | in Hg | ± 0.5 in Hg | ± 2% of * | Not Given |
| Inlet Pressure Above Atomspheric) | $P_I$ | Bar | PSIG | ± 2% of Maximum Measured Inlet Pressure | Not Given | Not Given |
| Outlet Pressure | $P_O$ | Bar | PSIG | ± 1% of Maximum Measured Outlet Pressure | ± 2% of * | ± 2% of * |
| Inlet Temperature | $\theta_I$ | °C | °F | ±.5°C (± 1°F) | ± .5°C | ± 2.8°C |
| Input Torque | $T_I$ | Newton-Meter | lb-in | ± 2% of Maximum Measured Torque | ± 1% of * | ± 1% of * |
| Case Drain Flow | $Q_L$ | Liter/Minute | GPM | ± 2% of Maximum Measured Case Drain Flow | Not Given | Not Given |
| Outlet Flow | $Q_O$ | Liter/Minute | GPM | ± 2% of Maximum Outlet Flow | ± 2% of * | ± 2% of * |

* The identified industrial standard does not specify the method by which the percentage is to be used to calculate the permitted error limit.

Minimum psi for 2 minutes

100% of maximum constant rated pressure for 2 minutes

Minimum psi for 2 minutes

115% of maximum constant rated pressure for 2 minutes

Minimum psi for 2 minutes

At each data point record input speed, torque, temperature, pressure and outlet temperature, pressure and flow.

5. Run the pump for two hours at constant rated speed and an outlet pressure of maximum constant rated outlet pressure. Monitor and record input speed, torque, temperature and outlet pressure, temperature, and flow every two minutes to determine changes in the overall efficiency.

6. At the conclusion of the two hour test, take an oil sample to determine the contamination level of the system.

1.4.2 Instrumentation and Test Parameter Accuracy - NFPA T3.9.17R1

The accuracy tables 1 and 2 of NFPA T3.9.17R1 were used as a basis for determining the measurement system for this test program. The values are being contested by industry, and a survey of T3.9.17 members is being conducted to obtain current estimates of more acceptable tolerance limits.

1.4.3 Reference Standards

1. NFPA T3.9.17R1 Proposed Method of Testing and Presenting Basic Performance Data for Positive Displacement Hydraulic Fluid Power Pumps and Motors.

2. NFPA T2.9.1-1972, ANSI B93.19-1972 Method for Extracting Fluid Samples from the Lines of Operating Hydraulic Fluid Power System for Particulate Contamination Analysis.

3. NFPA T2.9.2-1972, ANSI B93.20-1972 Procedure for Qualifying and Controlling Cleaning Methods for Hydraulic Fluid Power Fluid Sample Containers.

4. NFPA T2.9.6-1972, ANSI B93.28-1972 Method for Calibration of Liquid Automatic Particle Counters Using AC Fine Test Dust.

5. NFPA T2.9.3-1973, ANSI B93.30-1973 Method of Reporting Contamination Analysis Data of Hydraulic Fluid Power Systems.

6. SAE J745C-1970 Hydraulic Power Pump Test Procedure.

Minimum psi for 2 minutes

72% of maximum constant rated pressure for 2 minutes

Minimum psi for 2 minutes

110% of maximum constant rated pressure for 2 minutes

Minimum psi for 2 minutes

115% of maximum constant rated pressure for 2 minutes

Minimum psi for 2 minutes

At each data point record input speed, torque, temperature, pressure, and outlet temperature, pressure and flow.

7. Run the pump for two hours at constant rated speed and maximum constant rated outlet pressure. Monitor and record input speed, torque, temperature, pressure and outlet temperature, pressure, and flow every two minutes to determine changes in overall efficiency.

8. At the conclusion of the two hour test, take another oil sample to determine the contamination level of the system.

## Contaminated Fluid Break-In Procedure

1. Use the fluid conditioning circuit (Figure 1.5.13) to bring the system up to an operating temperature of 120°F.

2. Add uncut AC Fine Test Dust to the system and take oil samples until the contamination level is 1500 ± 250 particles per millilitre greater than 10 micrometres. Run with filters out of the circuit. (Do not operate the test pump.)

3. Start the test pump and bring the speed up to rated within one minute and maintain an outlet pressure less than 250 psi.

4. Load the pump at the following pressure increments and time intervals. (Do not readjust the speed for each load pressure.) The time interval between each pressure setting is one (1) minute.

Minimum psi for 2 minutes

24% of maximum constant rated pressure for 2 minutes

Minimum psi for 2 minutes

48% of maximum constant rated pressure for 2 minutes

Minimum psi for 2 minutes

72% of maximum constant rated pressure for 2 minutes

1.4 Test Requirements:

1.4.1 Development of the Break-In Test Procedure for Gear Pumps

The results of the gear pump break-in procedure survey were analyzed to develop a common break-in procedure for all eighteen gear pumps. The procedure for all eighteen gear pumps was identical except for the contamination level of the fluid. Twelve of the pumps, four from each manufacturer were broken-in using clean fluid with a contamination level of 100 particles per millilitre greater than ten micrometres. The remaining six pumps, two from each manufacturer were broken-in using dirty fluid with a contamination level of 1500 particles per millilitre greater than ten micrometres. The procedures developed were as follows:

Clean Fluid Break-In Procedure

1. Install the test specimen pump in test circuit shown in Figure 1.5.14. Before starting the test, take an oil sample to determine if the contamination level is 100 or less particles per millilitre greater than ten micrometres.

2. Use the fluid conditioning circuit (Figure 1.5.13) to bring the system up to 120°F operating temperature. (Do not operate the test pump.)

3. Start the test pump and bring the speed up to rated speed within one minute and maintain an outlet pressure less than 250 psi.

4. Leave the pump run for twenty minutes with the filters out of the system, then take an oil sample to determine the roll off cleanliness level of the pump.

5. Put the filters in the system and continue running the pump at rated speed with an outlet pressure less than 250 psi for twenty minutes to clean up the system. Take an oil sample to determine if the contamination level is within specifications. Leave the filters in the circuit for the remainder of the break-in test.

6. When the contamination level is within specified limits, load the pump at the following pressure increments and time intervals. Set speed initially at rated speed and minimum pressure. (Do not readjust the speed for each load pressure.) The time interval between each pressure setting is one (1) minute.

   Minimum psi for 2 minutes

   24% of maximum constant rated pressure for 2 minutes

   Minimum psi for 2 minutes

   48% of maximum constant rated pressure for 2 minutes

## 1.2 Test Objectives:

### 1.2.1 Primary Objectives

A. To prepare and sponsor a current revision to NFPA T3.9.17, Pump and Motor Test Procedures.

B. To prepare a proposal for revising the Fluid Power Measurement Methods of ISO/TC-131/SC-8/WG-3.

### 1.2.2 Secondary Objectives

A. To bring into consonance the needs of the U.S. Army, Industries technological capabilities and current thinking in the International Standards arena.

B. To investigate the extent to which gear pumps undergo irreversible degradation of efficiency in the first few hours of their lives.

C. To investigate the extent to which heavy doses of contaminant at break-in time will affect and/or expedite degradation of efficiencies.

D. To prepare test procedures which will accurately and repeatably assess the performances of pumps in view of today's energy conservation needs.

E. To estimate the spread in performance efficiencies which can be expected among several samples of conventional commercial gear pumps.

F. To investigate realistic U.S. Army acceptance criteria for pump performance efficiency.

G. To set up required measurement procedures and certify working instruments.

## 1.3 Component Description

The eighteen gear pumps tested were coded by arbitrarily selecting numbers from a random number chart in order to maintain confidentiality of the program participants. These numbers were then stamped on identification tags and attached to the individual pumps. In the process of testing, the code numbers were used to segregate the data collected. The three industrial contributors (final selection made by U.S. Army MERADCOM) each contributed 6 nominally identical gear pumps which were commercial industrial equivalents to pumps supplied to the U.S. Army for application on military equipment. The range of component specifications were as follows:

| Pressure (PSI) | Speed (RPM) | Displacement ($in^3$) |
|---|---|---|
| 2500-3000 | 2800-3000 | 2.8-3.16 |

INTENTIONALLY BLANK

1.1.3 A total of 18 gear pumps were solicited from each of 3 different manufacturers at no charge to MSOE in exchange for test reports. Each of the 6 pumps contributed to the program from each manufacturer were standard production pumps.

The U.S. Army (MERADCOM) selected the contributors from a list of manufacturers indicating an interest in participating in the program. The following contributors were selected:

| | |
|---|---|
| Company Name: | Hydreco<br>A unit of General Signal |
| Address: | 9000 E. Michigan Avenue<br>Kalamazoo, Michigan 49003 |
| Technical Contact: | Joe Lemon<br>Project Engineer |

| | |
|---|---|
| Company Name: | Sperry Vickers - North American Group |
| Address: | Troy, Michigan 48084 |
| Technical Contact: | Ron Imperati<br>Director of Engineering |

| | |
|---|---|
| Company Name: | Sta-Rite Industries, Inc.<br>Fluid Power Division<br>Webster Electric Co., Inc. |
| Address: | 1900 Clark Street<br>Racine, Wisconsin 53403 |
| Technical Contact: | Glenn Hubbard<br>Manager-Forward Planning |

1.1.4 Mail Survey Respondents

The gear pump manufacturers who responded to the Break-In Procedure Mail Survey are acknowledged below. Details of the survey may be found in part 2.0, section 2.2. Without their valuable input, a general gear pump break-in procedure could not have been developed.

1. Dana Corp. - Hillsdale Hydraulics
2. Sperry-Vickers
3. Parker-Hannifin Corp. - Mobile Hydraulics Div.
4. Hydreco
5. Roper Pump Co.
6. Ross Gear - Division of TRW
7. Fluids Control Division - LFE Corp.
8. FMC Corp. - Northern Ordance Div.
9. MTE Hydraulics, Inc.
10. Weatherhead Co. - Subsidiary of Dana Corp.
11. Webster Electric Co., Inc. - Sta-Rite Industries
12. Hydraulic Products, Inc.
13. Prince Manufacturing Corp.

BLOCK DIAGRAM OF OVERALL PUMP
INVESTIGATION PROGRAM
OF
CONTRACT #DAAK70-77-C-0214

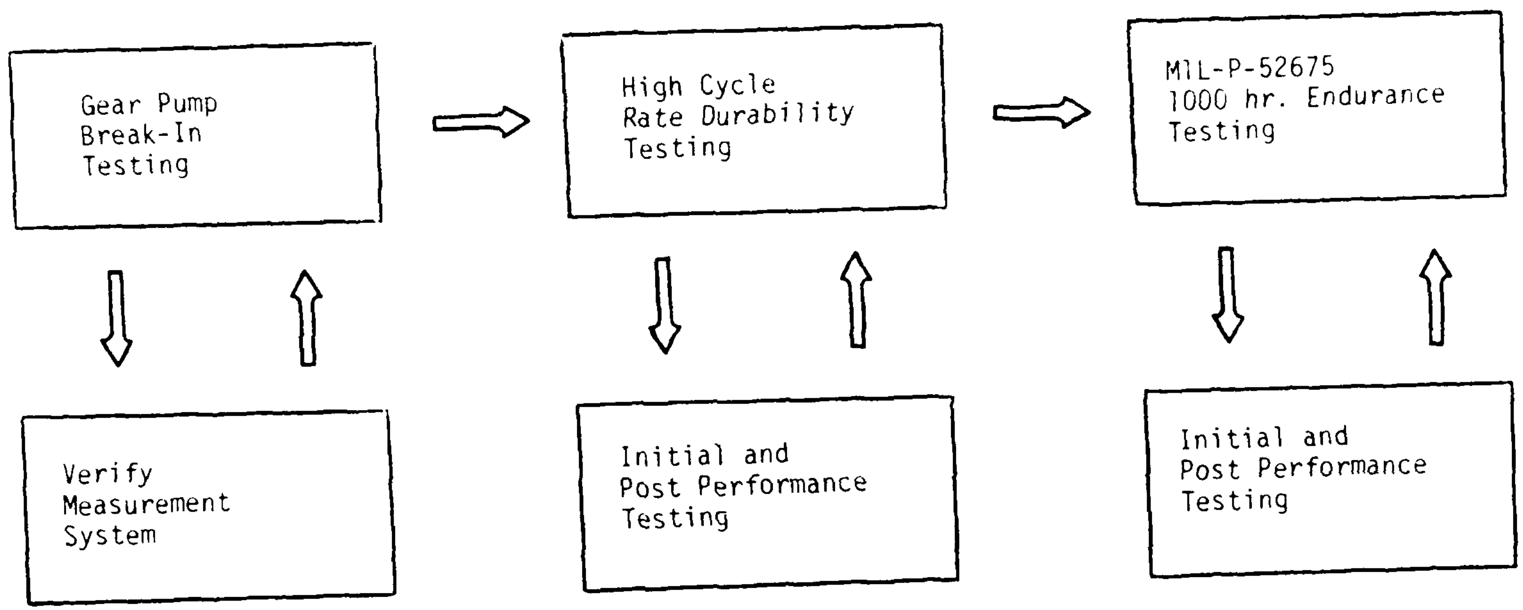



Figure 1.1.1

# PART 1.0 LABORATORY PROGRAM

## 1.1 Introduction:

### 1.1.1 Contents and Authorization

This interim report summarizes the results obtained in evaluating gear pump efficiencies during the first few hours of the pumps lives. This concludes the initial phase of the program to investigate pumps described in the following section.

The authorization for this program effort set forth in MSOE Fluid Power Institute unsolicited proposal entitled "A Proposal to Evaluate Hydraulic Pump Efficiencies During The First Few Hours of the Pumps Lives", dated May, 1977 was awarded on 30 September, 1977 under contract number DAAK70-77-C-0214.

### 1.1.2 Objectives of Contract

The overall program objectives are:

1. To prepare, implement, and validate a current version of NFPA's T3.9.17R1 Pump and Motor Test Procedure.
2. To determine the degree of correlation between the endurance test method in MIL-P-52675 and the high cycle rate durability test method.
3. To determine if the durability test method will serve as an acceptable accelerated life test to replace that procedure contained in the current version of MIL-P-52675.
4. To implement and validate those measurement procedures prepared by the Milwaukee School of Engineering for the U.S. Army under contract number DAAG53-76-C0036.

The means by which these objectives are to be accomplished is shown in figure 1.1.1.

The objectives of the effort reported herein support 1. and 2. of the overall program objectives and specifically for this phase were:

1. To evaluate Industry efforts of hydraulic pump break-in procedures upon the MSOE measured value of overall efficiency on a selected sample of 18 commercial grade gear pumps.
2. To study the nature of and the degree to which the overall efficiency migrates during the first few hours of the pumps' lives.
3. To determine the degree to which moderately heavy doses of AC fine test dust affect the above.

## BLOCK DIAGRAM OF MEASUREMENT SYSTEM

Section 1.5.3 Block diagram representation showing data acquisition system (DAS) connect to transducers.

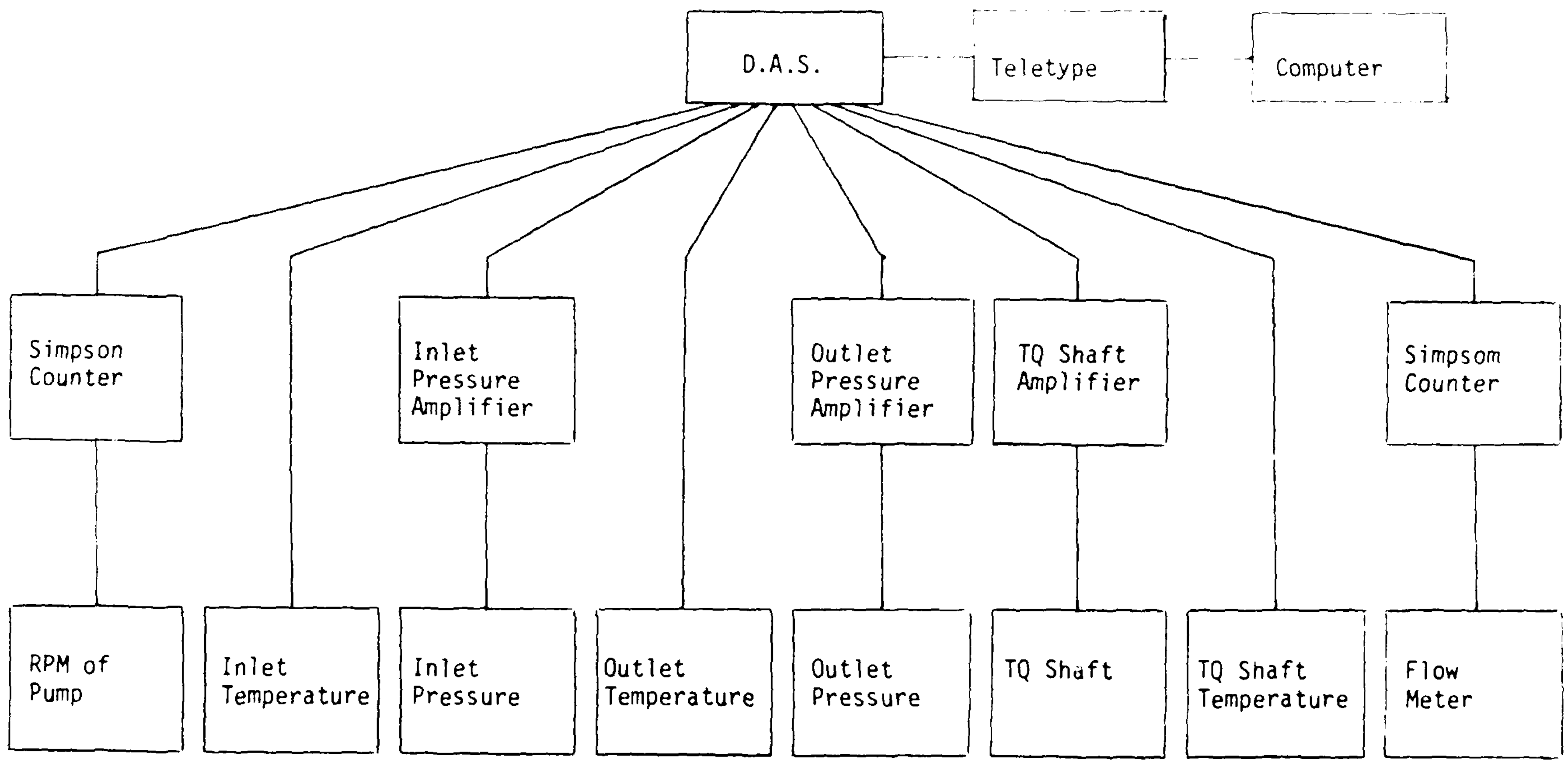



Figure 1.5.1

### 1.5.4 Test Instruments

All test parameter measurements (torque, pressure, speed, flow, and temperature) were recorded using the data acquisition. Hard copy of the recorded values was obtained using a Teletype terminal. Photos of test instruments follows.

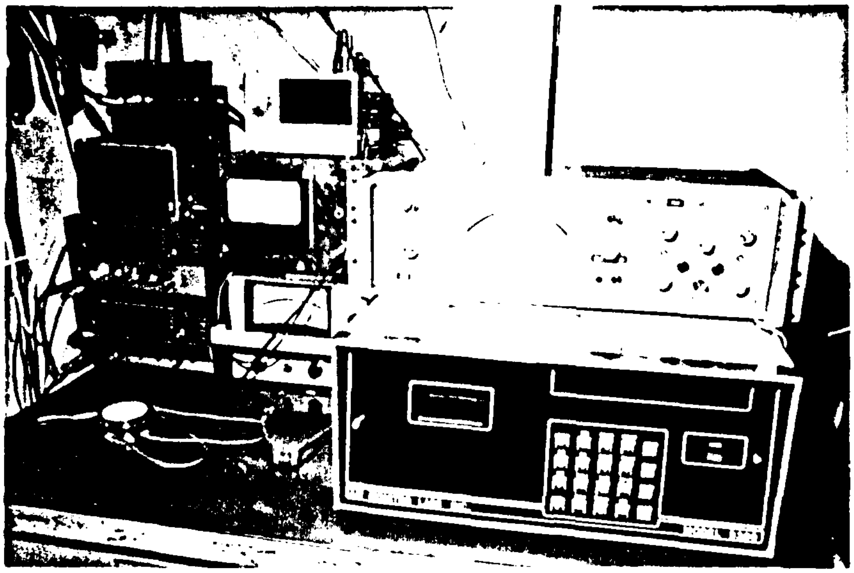


Figure 1.5.2

DATA ACQUISITION SYSTEM AND SUPPORTING INSTRUMENTATION

Data acquisition system on the right with Daytronics torque shaft amplifier on top. At left are the frequency counters used as readouts for flow rate and shaft speed. BCD output from counters transmitted data to DAS. In the middle are the Pace and Viatran pressure transducer power supplies.

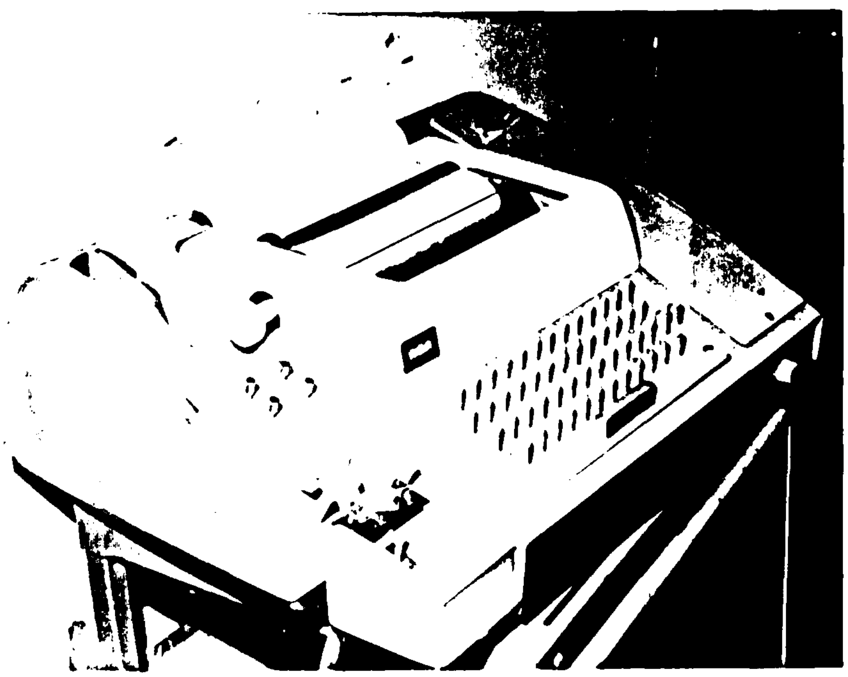


Figure 1.5.3

TELETYPE TERMINAL

Teletype terminal produced hard copy of recorded values and paper tape for entry into computer

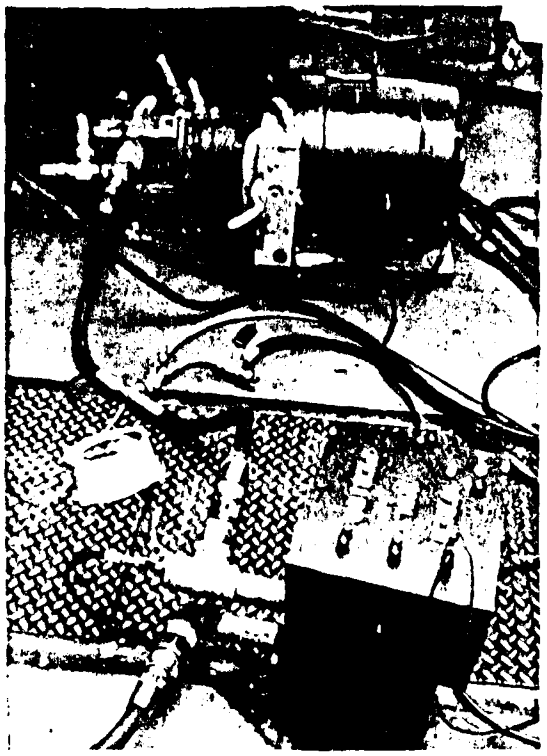


Figure 1.5.4

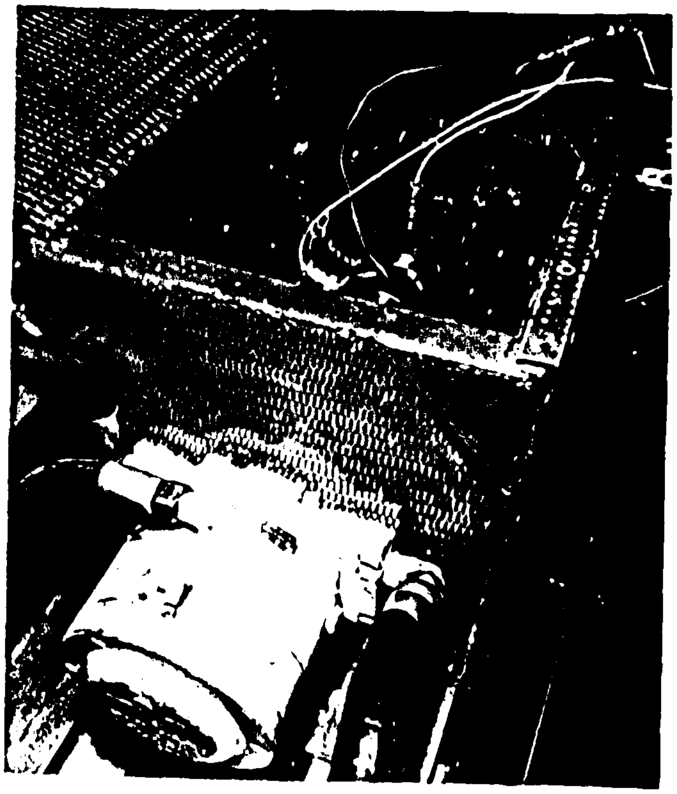
FLOWMETER

Flowrate was measured using a positive displacement flowmeter with a frequency output. Pictured is the FPI 10 cu. in/rev flowmeter.

Figure 1.5.5

DRIVE MOTORE AND TORQUE SHAFT

Shown is drive motor at bottom of photo connected to test pump thru torque shaft. Cables from inside safety cage are thermocouple, speed, and torque shaft signal leads. The thermocouple was used to monitor torque shaft housing temperature.



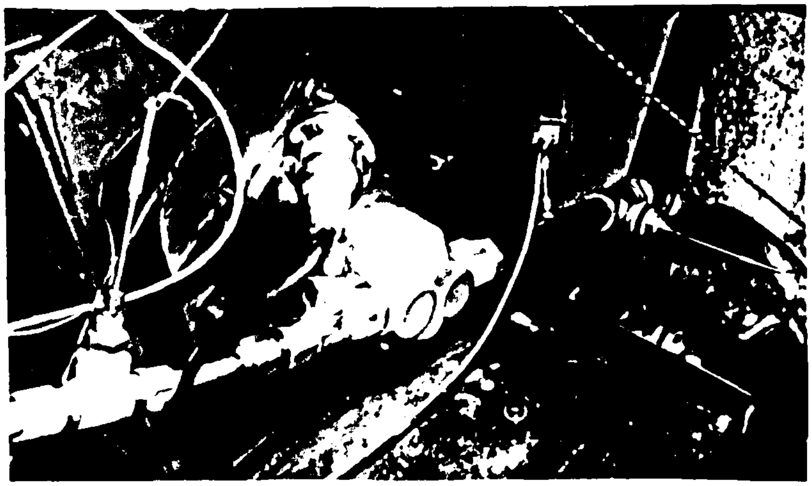


Figure 1.5.6

PRESSURE AND TEMPEARTURE TRANSDUCERS

Pressure and temperature measurements were made at the inlet and outlet of the test pump. The hose leading to the inlet of the pump was insulated to reduce temperature fluctuations when increasing and decreasing the pressure at the outlet.

[illegible] and Specifications of Power Unit

[illegible] Variable Volume hydraulic supply was used to power the drive motor on the test pump set-up.

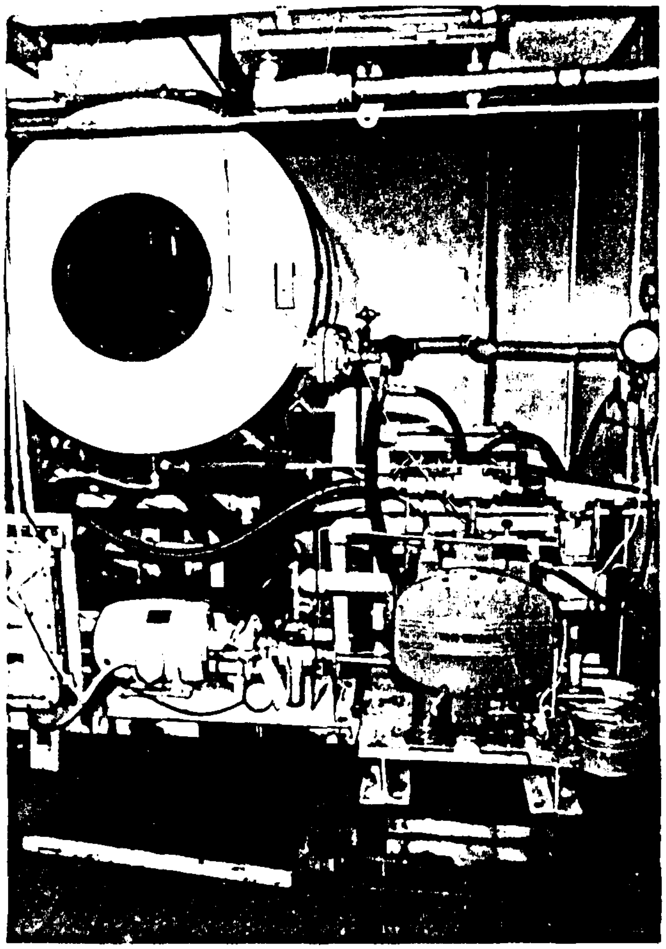


Figure 1.5.7

HYDRAULIC POWER SUPPLY

[illegible] the reservoir, variable volume pump, and the [illegible] mechanism. The servo supply (below the reservoir) [illegible] adjust the flow output from the Denison pump [illegible] turn, determined the speed of the drive motor

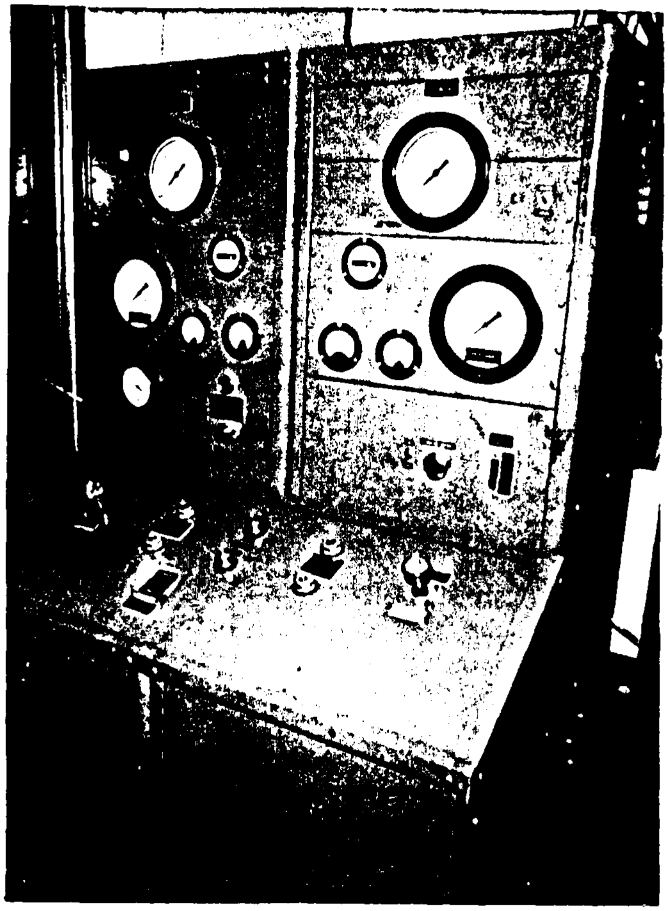


Figure 1.5.8

HYDRAULIC POWER SUPPLY CONTROL CONSOLE

The 300 H.P. main control console was used to start, stop, and monitor the output of the supply pump supplying power to the drive motor.

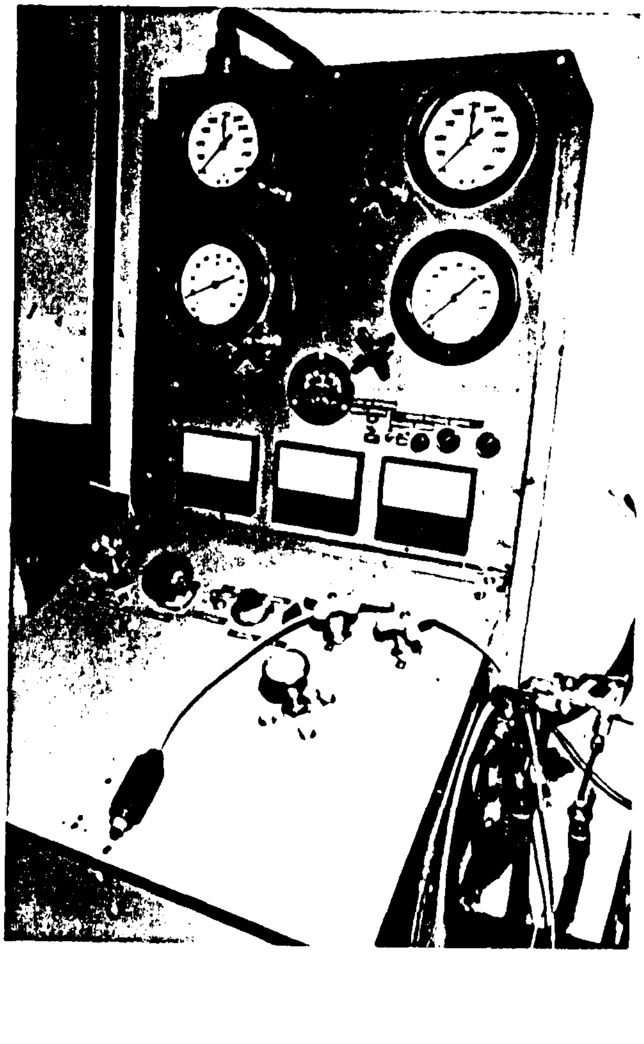


Figure 1.5.9

HYDRAULIC POWER SUPPLY REMOTE CONTROL CONSOLE

After the supply pump was started, control of the supply pump was transferred to the remote console which was located in the test cell. The outlet pressure of the test pump was also monitored at the remote console. A black switch with cable shown center of console was used to trigger DAS for data collection.

## FPI HYDRAULIC SCHEMATIC FOR 300 HP TEST SUPPLY

Section 1.5.6 Schematic of central hydraulic supply used in conjunction with Figure 1.5.14

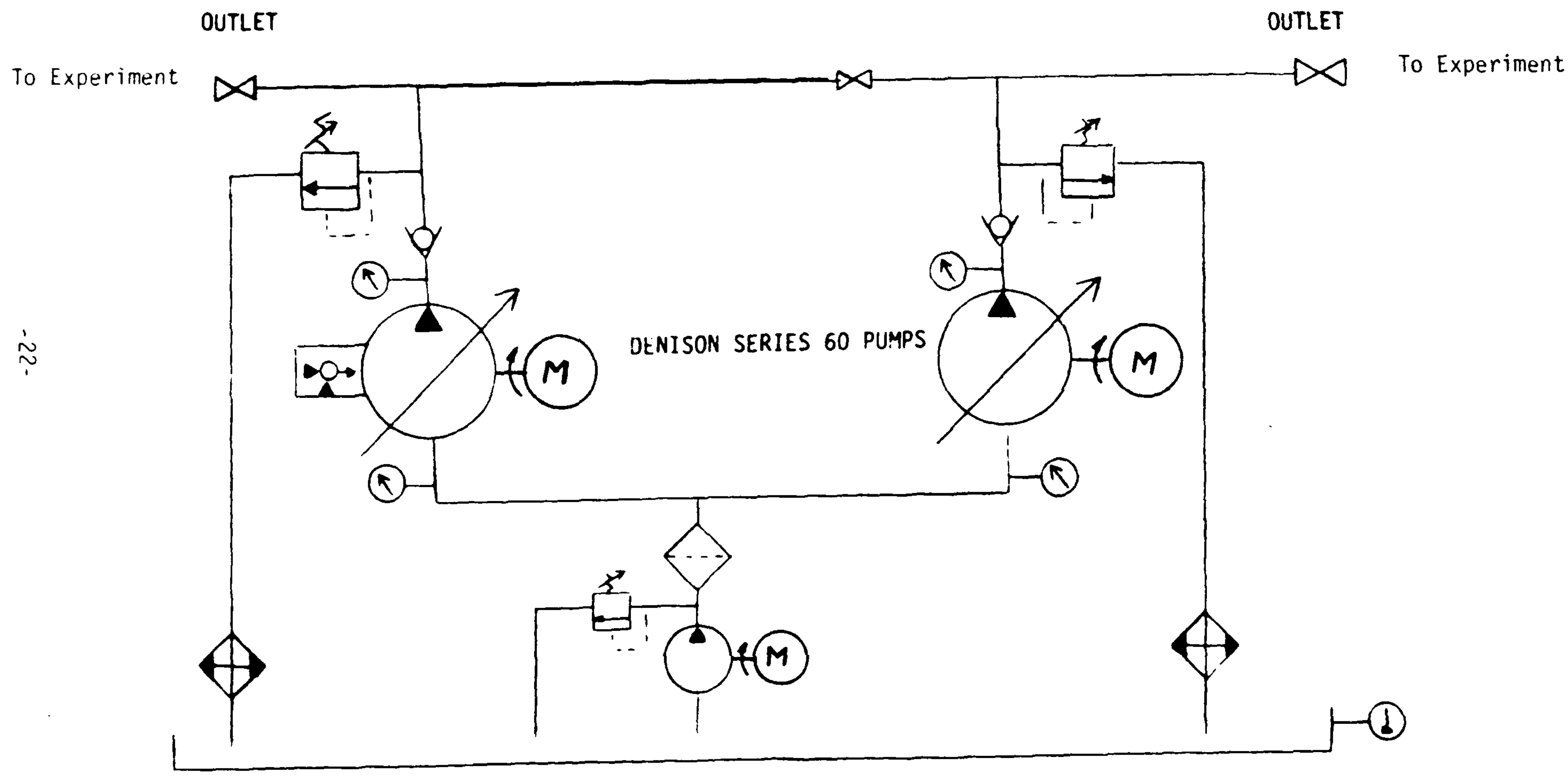



Figure 1.5.10

## [illegible] Test Facility Description

The test circuit consisted of a hydraulic drive motor coupled to the test pump thru the torque shaft. Power to the drive motor was supplied by FPI's 300 H.P. main hydraulic supply. A piloted relief valve was used to control pump load pressure. A separate fluid conditioning circuit consisting of a circulating pump, electrical heater and heat exchanger was installed to establish the required fluid temperature and contamination level prior to break-in testing.

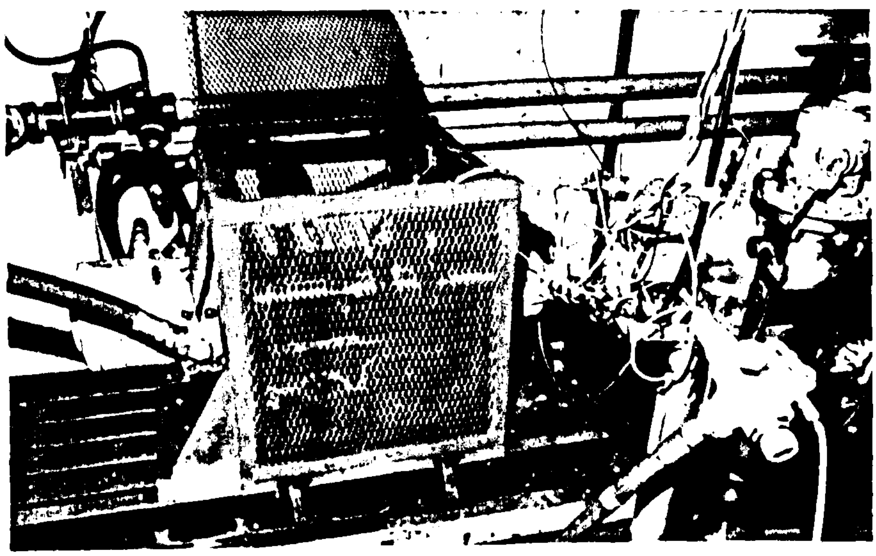


Figure 1.5.11

TEST CIRCUIT AND COMPONENTS

[illegible] showing drive motor coupled to test pump thru torque shaft. The relief valve was used to control pump load pressure.

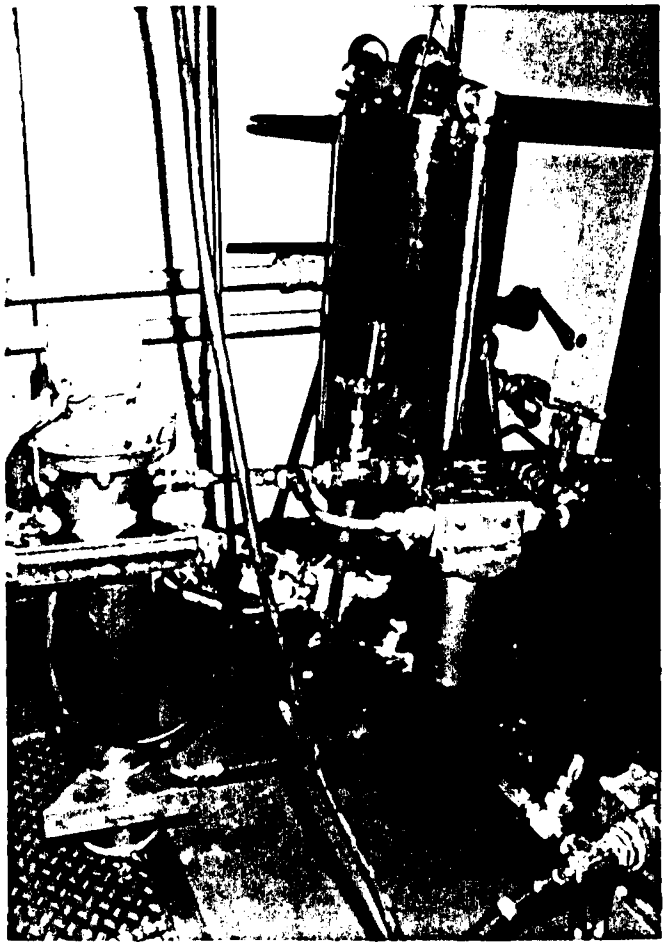


Figure 1.5.12

FLUID CONDITIONING SYSTEM

Fluid conditioning system consisting of reservoir with conically [illegible] bottom, filter, strainer, and electrical heater. At extreme bottom right corner of photo is the circulating pump. Heat exchanger (not visible) was mounted vertically to the back of the reservoir.

FLUID CONDITIONING SYSTEM

BREAK-IN & PERFORMANCE TESTS

Section 1.5.8 Schematic of fluid conditioning flow loop system used to establish the required fluid temperature and contamination level.

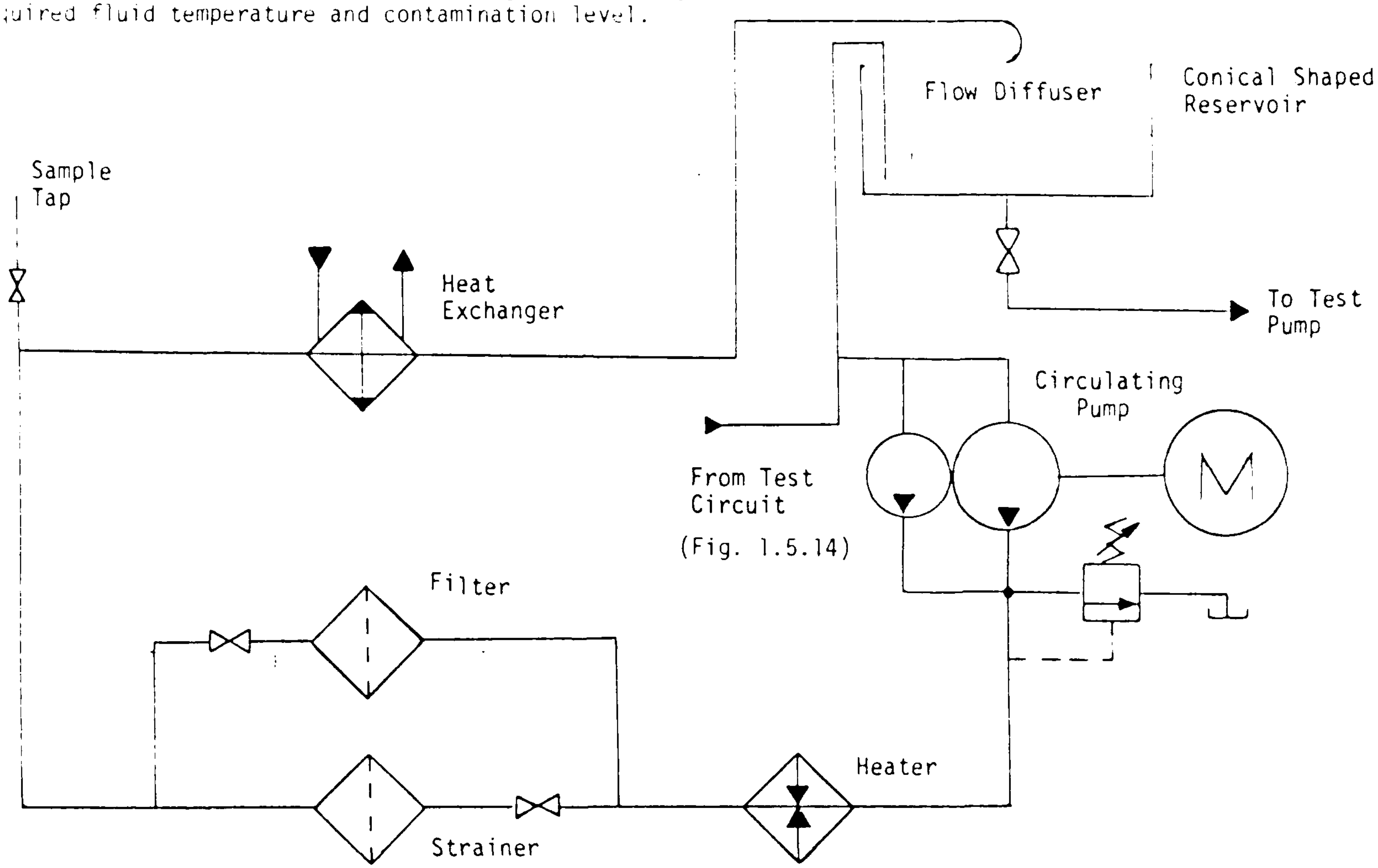



Figure 1.5.13

BREAK-IN & PERFORMANCE
TEST CIRCUIT

Section 1.5.9 Schematic of test circuit for break-in and performance testing.

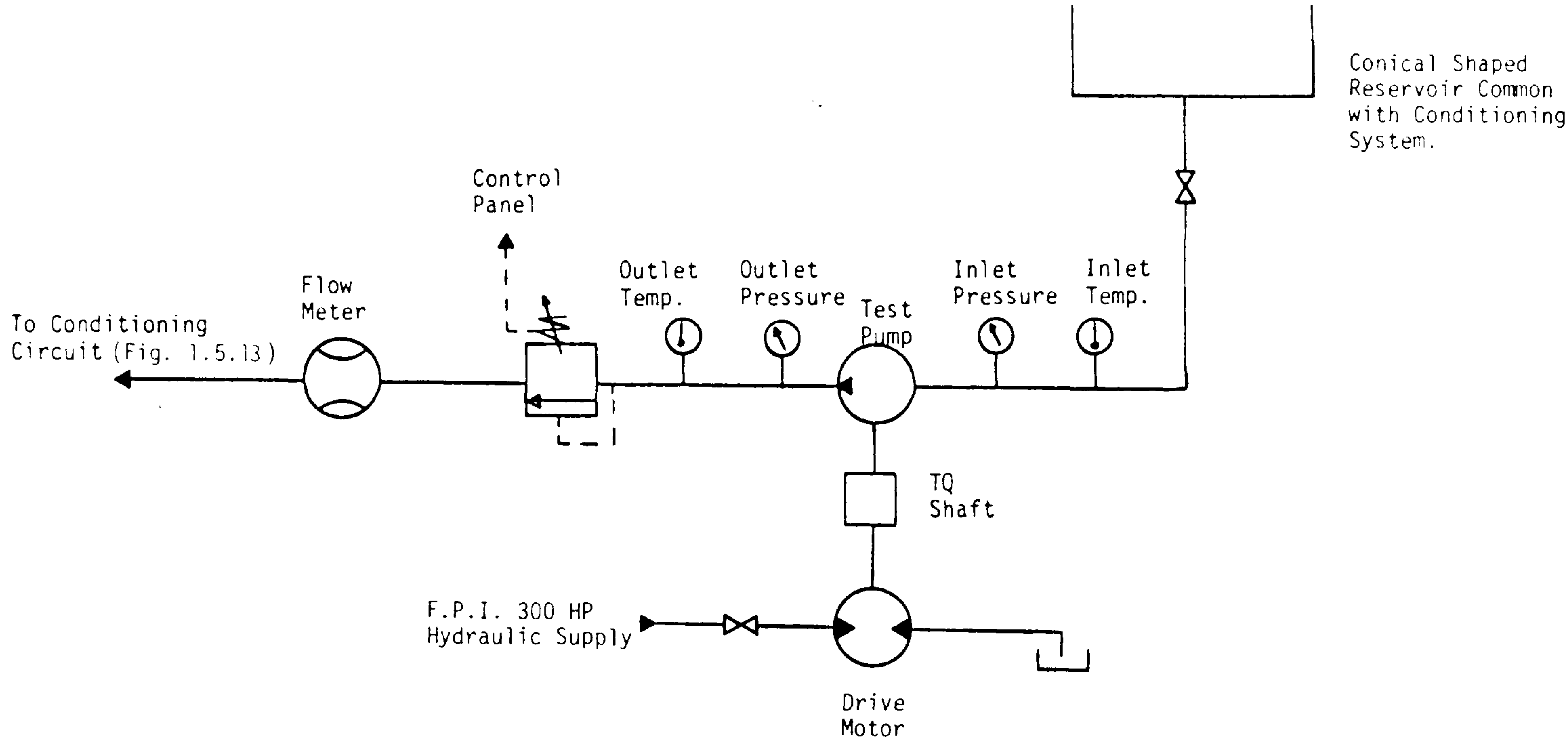



Figure 1.5.14

## 1.6 Gear Pump Test Procedure

### 1.6.1 Introduction

Before the eighteen gear pumps supplied by industry were tested, the test system was qualified using one of FPI's gear pumps. Both the hydraulic circuit and the instrumentation system were qualified.

### 1.6.2 Hydraulic Circuit Qualification

A twenty gallon cylindrical shaped reservoir with a conical bottom was used to insure that no contaminant could settle to the bottom. A diffuser was installed in the center of the reservoir just below the oil level which created a mixing action inside the reservoir to keep the contaminants in uniform suspension. A separate fluid conditioning circuit was incorporated into the main hydraulic circuit for heating or cooling the oil and to control the contamination level. A three micrometre nominal filter was used in the fluid conditioning circuit with a bypass valve so the fluid could be either routed through the filter or around it. When the fluid bypassed the filter, it went through a sixty micrometre strainer to remove the large particles. The sample tap was installed in an elbow in the return line after the filter and strainer.

To qualify the system, the fluid conditioning circuit and the FPI pump were run for several hours with the filter in the circuit. Oil samples were taken at selected intervals to monitor the stability of the contamination level. The system was contaminated with AC Fine Test Dust to the level required for the contaminated fluid break-in and allowed to run for several hours with the filters out of the circuit. Oil samples were taken at selected intervals to monitor the stability of the contamination level. The thermal stability of the system was also monitored during this time. Qualification results are shown on page 28, figure 1.6.1.

### 1.6.3 Instrumentation System Qualification

The transducers and their related equipment listed in part 1.5.1 and calibrated as described in parts 2.4 through 2.8 of this report were installed in the test circuit, figure 1.5.14. The outputs from all the transducer amplifiers were connected to a single data acquisition system which was completely controlled by the operator. The data acquisition system was used as an interface device to output data from the transducer amplifiers onto a paper tape and teletype. The paper tape with the raw data was fed into a Burroughs computer for processing.

Calibration of the instrumentation system was verified before and after the break-in test on each gear pump. The FPI gear pump was installed in the test circuit to check out the operation of all the transducers, data acquisition system, and the teletype before testing the eighteen gear pumps supplied by industry.

### 1.6.4 Deviations from Test Requirements

The actual test procedure followed is as presented in section 1.4.1 of this report for break-in of the gear pumps.

TEST CIRCUIT CONTAMINATION LEVEL STABILITY AFTER ADDING
1.5 GRAMS OF UNCUT ACFTD IN THE FIRST 75 MINUTES

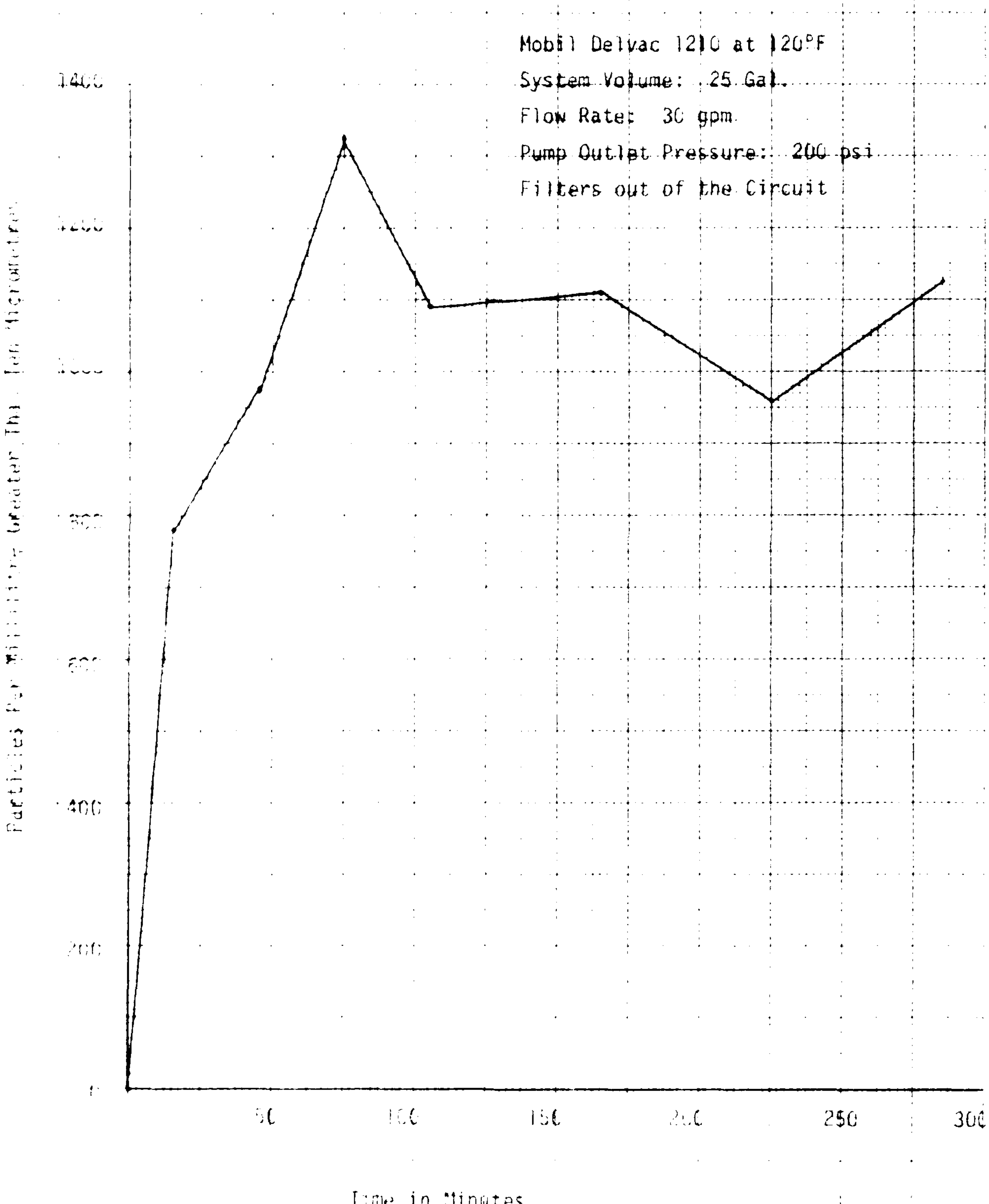



Figure [illegible]

## 1.7 Results - Cyclic Break-In and Two Hour Run

### 1.7.1 Method of Data Processing

Data was processed using FPI's LABCAL computer report Processing Program. Prior to execution of this program, the input information was separated into three categories of data files:

1. Transducer File (calibration data)
2. Raw Data File (laboratory data)
3. Instruction File (data manipulation information)

Upon execution, the raw data file is automatically run through the transducer file. This corrects the raw data, as recorded in the laboratory, to standard engineering units and provides for calibration corrections. The resultant data is then mathematically manipulated to yield required information by means of the instruction file.

Output information from LABCAL is in the form of graphically plotted data, data tables, and summary data.

### 1.7.2 Data Adjustments

During the cyclic break-in, changes in the input speed to the pump occurred due to different values of loading. With the largest pump, the maximum loss in speed was 269 rpm (no-load to full-load), or about 10% of Target Speed. Because of time limits established for data collection, the input speed could not be adjusted at each loading to a constant 2700 RPM. This input speed drop-off meant that the output flow also dropped off. These flow values were adjusted using a ratio of the target speed and the actual measured speed:

$$Q\ adj. = (N_T\ Q_m)/N_A$$

Flow values for the two hour run were also adjusted to compensate for slight changes from the target speed using the same mathematical procedure as in the cyclic break-in. Input torque values, for the two hour run were adjusted to compensate for slight changes in outlet pressure (less than 1% of target pressure) by using a ratio for the target pressure and the actual measured pressure:

$$T\ adj. = (P_T\ T_m)/P_A$$

An additional torque adjustment was performed to correct for torque readings affected by temperature changes within the torque shaft.

In Sections 1.7.3-1.7.4 Tabulated Data, the "% of ideal torque" can exceed a value of 100% since the torque input in the case of [illegible] pumps must be greater than that calculated on the basis of pump displacement and outlet pressure alone.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

T 1 : PUMP CODE NO. 17353 - 120 DEG. F.
TION 1.03 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL VALUE | MECH. EFFICIENCY PERCENT | VOL. EFFICIENCY PERCENT | OVERALL EFFICIENCY PERCENT |
|---|---|---|---|---|---|
| 68 | [illegible] | [illegible] | [illegible] | [illegible] | 85.234 |
| 69 | [illegible] | [illegible] | 95.779 | 88.953 | [illegible] |
| 70 | [illegible] | [illegible] | [illegible] | [illegible] | 87.168 |
| 71 | [illegible] | 102.323 | 97.730 | 89.051 | [illegible] |
| 72 | 120.000 | 102.164 | 97.882 | 89.105 | 87.266 |

PART 1 : PUMP CODE NO. 18103 - 120 DEG. F.
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL VALUE | MECH. EFFICIENCY PERCENT | VOL. EFFICIENCY PERCENT | OVERALL EFFICIENCY PERCENT |
|---|---|---|---|---|---|
| 70 | [illegible] | [illegible] | 95.674 | [illegible] | [illegible] |
| 71 | [illegible] | [illegible] | 95.162 | [illegible] | 86.507 |
| 72 | [illegible] | 104.725 | 95.480 | [illegible] | [illegible] |
| 73 | 122.000 | [illegible] | 95.052 | 90.873 | 86.769 |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

RT 1 : PUMP CODE NO. 15459 - 120 DEG. F.
CTION 1.09 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF [illegible] | MECH. EFFICIENCY PERCENT | VOL. EFFICIENCY PERCENT | OVERALL EFFICIENCY PERCENT |
|---|---|---|---|---|---|
| 12 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 13 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 14 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 17 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 19 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 20 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
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| 22 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 24 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 25 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 26 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 27 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 29 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 31 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 32 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
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| 44 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
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| 66 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
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| 68 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 69 | [illegible] | 103.472 | [illegible] | 93.982 | [illegible] |
| 70 | [illegible] | 101.259 | 98.757 | [illegible] | 92.972 |
| 71 | [illegible] | 100.868 | 99.134 | 93.982 | 93.203 |
| 72 | 120.000 | 100.749 | 99.257 | 93.935 | 93.266 |

PART 1 : PUMP CODE NO. 05585 - 120 DEG. F.
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF [illegible] | MECH. EFFICIENCY PERCENT | VOL. EFFICIENCY PERCENT | OVERALL EFFICIENCY PERCENT |
|---|---|---|---|---|---|
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| 12 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 13 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
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| 59 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
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| 67 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 68 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 69 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 70 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 71 | 118.000 | 103.900 | [illegible] | [illegible] | [illegible] |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 : PUMP CODE NO. 56991 - 120 DEG. F.
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME MINUTES | % OF IDEAL | MECH. EFF. PERCENT | VOL. EFF. PERCENT | OVER-ALL EFF. PERCENT |
|---|---|---|---|---|---|
| 12 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 13 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 14 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 17 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 19 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 20 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 21 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 22 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 24 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 25 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 26 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 27 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 29 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 31 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 32 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 33 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 34 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 35 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 36 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 39 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 40 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 41 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 42 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 43 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 44 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 45 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 46 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 47 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 49 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 50 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 51 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 52 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 53 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 54 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 55 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 56 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 57 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 59 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 60 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 61 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 63 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 64 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 65 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 66 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 67 | [illegible] | 100.887 | 99.121 | 93.178 | 92.386 |
| 68 | 112.000 | 100.472 | 99.531 | 93.213 | 92.805 |

PART 1 : PUMP CODE NO. 1195A - 120 DEG. F.
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUI

PROCESSED DATA

| | TIME MINUTES | % OF IDEAL | MECH. EFF. PERCENT | VOL. EFF. PERCENT | OVER-ALL EFF. PERCENT |
|---|---|---|---|---|---|
| 12 | [illegible] | [illegible] | 93.295 | [illegible] | [illegible] |
| 13 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 14 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 17 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 19 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 20 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 21 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 22 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 24 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 25 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 26 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 27 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 29 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 31 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 32 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 33 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 34 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 35 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 36 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 39 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 40 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 41 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 42 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 43 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 44 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 45 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 46 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 47 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 49 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 50 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 51 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 52 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 53 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 54 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 55 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 56 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 57 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 59 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 60 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 61 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 63 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 64 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 65 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 66 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 67 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 68 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 69 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 70 | [illegible] | 100.738 | [illegible] | [illegible] | [illegible] |
| 71 | 118.000 | 100.607 | 99.397 | 93.509 | [illegible] |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 ; PUMP CODE NO. 25331 - 120 DEG. F.
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | [illegible] | 108.108 | 92.520 | 92.550 | 85.691 |
| 13 | [illegible] | [illegible] | 92.510 | [illegible] | 85.539 |
| 14 | [illegible] | [illegible] | 93.134 | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | 92.512 | [illegible] | [illegible] |
| 16 | [illegible] | [illegible] | 92.334 | [illegible] | 85.120 |
| 17 | [illegible] | 108.228 | 92.397 | 92.105 | [illegible] |
| 18 | [illegible] | [illegible] | 92.581 | [illegible] | 85.206 |
| 19 | [illegible] | [illegible] | 92.724 | 92.012 | 85.305 |
| 20 | [illegible] | [illegible] | 92.349 | 91.913 | [illegible] |
| 21 | [illegible] | [illegible] | [illegible] | 91.952 | [illegible] |
| 22 | [illegible] | [illegible] | 92.470 | 91.952 | [illegible] |
| 23 | [illegible] | [illegible] | 92.215 | 91.927 | 84.760 |
| 24 | [illegible] | [illegible] | 92.214 | 91.986 | [illegible] |
| 25 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 26 | [illegible] | [illegible] | 91.926 | [illegible] | [illegible] |
| 27 | [illegible] | [illegible] | 92.215 | [illegible] | 84.783 |
| 28 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 29 | [illegible] | [illegible] | 91.853 | 92.012 | 84.505 |
| 30 | [illegible] | [illegible] | 91.938 | [illegible] | 84.570 |
| 31 | [illegible] | [illegible] | 91.535 | [illegible] | 84.339 |
| 32 | [illegible] | [illegible] | 92.175 | 91.918 | 84.718 |
| 33 | [illegible] | [illegible] | 91.574 | 92.012 | [illegible] |
| 34 | [illegible] | [illegible] | 91.746 | [illegible] | [illegible] |
| 35 | [illegible] | [illegible] | 91.604 | [illegible] | [illegible] |
| 36 | [illegible] | [illegible] | 91.712 | [illegible] | [illegible] |
| 37 | [illegible] | [illegible] | [illegible] | [illegible] | 84.226 |
| 38 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 39 | [illegible] | [illegible] | 91.576 | [illegible] | [illegible] |
| 40 | [illegible] | [illegible] | 92.107 | [illegible] | 84.770 |
| 41 | [illegible] | [illegible] | 91.748 | [illegible] | [illegible] |
| 42 | [illegible] | [illegible] | 91.926 | 91.918 | [illegible] |
| 43 | [illegible] | [illegible] | 91.819 | 91.918 | 84.387 |
| 44 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 45 | [illegible] | [illegible] | [illegible] | [illegible] | 84.152 |
| 46 | [illegible] | [illegible] | [illegible] | [illegible] | 84.275 |
| 47 | [illegible] | [illegible] | 91.556 | [illegible] | 84.185 |
| 48 | [illegible] | [illegible] | 91.708 | [illegible] | 84.372 |
| 49 | [illegible] | [illegible] | 92.068 | [illegible] | 84.703 |
| 50 | [illegible] | [illegible] | 91.750 | [illegible] | 84.352 |
| 51 | [illegible] | [illegible] | 91.421 | [illegible] | 84.133 |
| 52 | [illegible] | [illegible] | 92.140 | [illegible] | [illegible] |
| 53 | [illegible] | [illegible] | 92.320 | [illegible] | 84.965 |
| 54 | [illegible] | [illegible] | [illegible] | [illegible] | 84.700 |
| 55 | [illegible] | [illegible] | [illegible] | [illegible] | 84.700 |
| 56 | [illegible] | [illegible] | 92.357 | 92.012 | 84.959 |
| 57 | [illegible] | [illegible] | 91.849 | 91.952 | [illegible] |
| 58 | [illegible] | [illegible] | [illegible] | 92.046 | 84.734 |
| 59 | [illegible] | [illegible] | 92.357 | 92.046 | 85.000 |
| 60 | [illegible] | 108.277 | 92.356 | 91.918 | [illegible] |
| 61 | [illegible] | [illegible] | [illegible] | 91.952 | [illegible] |
| 62 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 63 | [illegible] | [illegible] | [illegible] | [illegible] | 82.614 |
| 64 | [illegible] | [illegible] | [illegible] | 92.080 | 84.803 |
| 65 | [illegible] | [illegible] | 92.579 | 91.893 | 85.063 |
| 66 | [illegible] | 108.053 | 92.543 | 91.986 | 85.116 |
| 67 | 2.000 | 108.811 | 92.071 | 91.952 | 84.651 |
| 68 | 2.000 | 107.801 | 92.763 | 92.021 | 85.351 |

PART 1 ; PUMP CODE NO. 80378 - 120 DEG. F.
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | [illegible] | [illegible] | 91.538 | [illegible] | [illegible] |
| 13 | 2.000 | [illegible] | 92.032 | [illegible] | [illegible] |
| 14 | 4.000 | [illegible] | 91.599 | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | 91.779 | [illegible] | [illegible] |
| 16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 17 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 19 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 20 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 21 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 22 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 24 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 25 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 26 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 27 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 29 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 31 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 32 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 33 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 34 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 35 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 36 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 39 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 40 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 41 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 42 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 43 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 44 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 45 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 46 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 47 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 49 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 50 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 51 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 52 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 53 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 54 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 55 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 56 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 57 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 59 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 60 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 61 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 63 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 64 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 65 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 66 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 67 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 68 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 69 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 70 | [illegible] | 109.257 | 91.527 | [illegible] | [illegible] |
| 71 | 118.000 | 108.787 | 91.933 | [illegible] | [illegible] |
| 72 | 120.000 | 109.258 | 91.526 | 90.269 | 82.505 |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

RT 1 : PUMP CODE NO. 57730 - 120 DEG. F.
CTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | 0.000 | 111.429 | 89.745 | 90.250 | 80.983 |
| 13 | 2.000 | 110.959 | 90.123 | 90.064 | 81.158 |
| 14 | 4.000 | 111.715 | 90.322 | 90.129 | 81.452 |
| 15 | 6.000 | [illegible].772 | 90.[illegible] | 90.231 | 81.954 |
| 16 | 8.000 | 110.580 | 90.432 | 90.157 | 81.521 |
| 17 | 10.000 | 110.330 | 90.638 | 90.130 | 81.682 |
| 18 | 12.000 | 110.455 | 90.534 | 90.157 | 81.613 |
| 19 | 14.000 | 110.283 | 90.670 | 90.250 | 81.825 |
| 20 | 16.000 | 110.415 | 90.567 | 90.250 | 81.727 |
| 21 | [illegible] | [illegible].[illegible]41 | 90.530 | 90.183 | 81.633 |
| 22 | [illegible] | [illegible] | 90.533 | 90.190 | 81.642 |
| 23 | [illegible] | [illegible] | 90.741 | 90.283 | 81.913 |
| 24 | [illegible] | [illegible].265 | 90.707 | 90.157 | 81.768 |
| 25 | [illegible] | [illegible].492 | 90.910 | 90.257 | 81.[illegible] |
| 26 | [illegible] | 110.241 | 90.710 | 90.178 | 81.790 |
| 27 | [illegible] | 110.712 | 90.775 | 90.283 | 81.945 |
| 28 | [illegible] | 110.713 | 90.325 | 90.317 | 81.568 |
| 29 | [illegible] | 111.[illegible] | 90.555 | 90.317 | 81.765 |
| 30 | [illegible] | 111.072 | 90.332 | 90.374 | 81.310 |
| 31 | [illegible] | 111.257 | 90.672 | 90.257 | 81.828 |
| 32 | [illegible] | [illegible].[illegible]52 | 91.023 | [illegible].913 | 8[illegible].921 |
| 33 | [illegible] | [illegible].[illegible]22 | 91.089 | 90.105 | 82.066 |
| 34 | [illegible] | [illegible].[illegible]75 | 90.[illegible]6 | 90.271 | 81.998 |
| 35 | [illegible] | [illegible].829 | 91.053 | 90.271 | 82.189 |
| 36 | [illegible] | [illegible].779 | 91.[illegible]2 | 90.231 | 82.183 |
| 37 | [illegible] | 110.157 | 90.750 | 90.231 | 81.901 |
| 38 | [illegible] | [illegible] | 91.103 | 90.238 | 82.253 |
| 39 | [illegible] | [illegible] | 91.[illegible]2 | 90.232 | 82.121 |
| 40 | [illegible] | 109.607 | 91.235 | 90.298 | 82.373 |
| 41 | [illegible] | 109.608 | 91.23[illegible] | 90.278 | 82.372 |
| 42 | [illegible] | 109.352 | 91.[illegible] | 90.331 | 82.597 |
| 43 | [illegible] | 111.[illegible]72 | 90.[illegible]9 | 90.111 | 82.827 |
| 44 | [illegible] | [illegible].[illegible]21 | 91.639 | 90.264 | 82.724 |
| 45 | [illegible] | [illegible].653 | 91.137 | [illegible].016 | 81.170 |
| 46 | [illegible] | [illegible].[illegible]54 | 91.[illegible]93 | 90.271 | 82.757 |
| 47 | [illegible] | 109.611 | 91.231 | 90.271 | 82.3[illegible]5 |
| 48 | [illegible] | [illegible].[illegible]72 | 91.755 | 90.3[illegible]5 | 82.[illegible]59 |
| 49 | [illegible] | [illegible].[illegible]95 | 91.553 | 90.2[illegible]4 | 82.[illegible]74 |
| 50 | [illegible] | [illegible].[illegible]67 | 91.229 | 90.290 | 82.[illegible]27 |
| 51 | [illegible] | [illegible].[illegible]6 | 91.837 | 90.231 | 82.912 |
| 52 | [illegible] | [illegible].[illegible]71 | 91.515 | 90.231 | 82.555 |
| 53 | [illegible] | [illegible].[illegible]39 | 91.[illegible]20 | 90.[illegible]7 | 82.[illegible]5 |
| 54 | [illegible] | [illegible] | 91.[illegible]1 | 90.[illegible]4 | 82.[illegible]8 |
| 55 | [illegible] | [illegible] | 91.[illegible]3 | [illegible] | 82.[illegible]2 |
| 56 | [illegible] | [illegible].[illegible]75 | 92.[illegible]7 | 90.[illegible]97 | 82.[illegible]3 |
| 57 | [illegible] | [illegible].[illegible]25 | 91.3[illegible] | 90.[illegible]24 | 82.355 |
| 58 | [illegible] | [illegible].[illegible]67 | 91.258 | 90.231 | 82.[illegible]3 |
| 59 | [illegible] | [illegible].698 | 91.159 | 90.231 | [illegible] |
| 60 | 96.000 | 110.126 | 90.807 | 90.231 | 81.920 |
| 61 | [illegible] | 109.735 | 91.[illegible]8 | [illegible] | 8[illegible].3[illegible] |
| 62 | [illegible] | [illegible].[illegible]23 | 91.[illegible]5 | 90.[illegible]2[illegible] | 82.[illegible]3 |
| 63 | [illegible] | [illegible].[illegible]92 | 91.[illegible]5 | 90.[illegible]97 | 82.[illegible] |
| 64 | [illegible] | [illegible].[illegible]12 | 91.[illegible]5 | 90.317 | 82.[illegible]2 |
| 65 | [illegible] | [illegible].[illegible]27 | 91.[illegible] | 90.3[illegible]3 | 82.[illegible] |
| 66 | [illegible] | [illegible].[illegible]40 | 91.3[illegible] | 90.[illegible] | 82.523 |
| 67 | 11[illegible].000 | 109.271 | 91.515 | 90.350 | 82.[illegible]74 |
| 68 | 112.000 | 109.007 | 91.737 | 90.317 | 82.848 |

PART 1 : PUMP CODE NO. 125[illegible] - 120 DEG. F.
SECTION 1.0[illegible] : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | 0.000 | 107.016 | 9[illegible].[illegible]6 | 87.314 | 81.5[illegible]1 |
| 13 | 2.000 | 107.[illegible]42 | 93.334 | 87.597 | 81.[illegible]4 |
| 14 | 4.000 | [illegible] | 93.[illegible] | 87.564 | 81.[illegible]0 |
| 15 | 6.000 | [illegible].5[illegible]5 | 93.[illegible] | 87.690 | 8[illegible].3[illegible] |
| 16 | 8.000 | [illegible] | 93.[illegible] | 87.690 | 82.127 |
| 17 | 10.000 | [illegible].[illegible]7 | 93.[illegible]2 | 87.[illegible] | 82.[illegible]55 |
| 18 | 12.000 | 107.017 | 93.[illegible]3 | 87.816 | 82.048 |
| 19 | 14.000 | [illegible].[illegible]73 | 93.[illegible]30 | 87.909 | 82.299 |
| 20 | 16.000 | [illegible].848 | 93.550 | 88.002 | 82.320 |
| 21 | 18.000 | [illegible].803 | 93.630 | 88.127 | 82.5[illegible]3 |
| 22 | 20.000 | [illegible].762 | 93.[illegible]0 | 88.253 | 82.[illegible]3 |
| 23 | 22.000 | [illegible].506 | 93.[illegible]5 | [illegible] | 82.[illegible]2 |
| 24 | 24.000 | 107.015 | 93.257 | 8[illegible].[illegible]3 | 82.[illegible] |
| 25 | 26.000 | 107.331 | 93.2[illegible]0 | 8[illegible].[illegible]5 | 82.[illegible]4 |
| 26 | 28.000 | 107.227 | 93.[illegible]74 | 88.22[illegible] | 82.[illegible] |
| 27 | 30.000 | 107.[illegible]1 | 93.[illegible]60 | 88.1[illegible]8 | 82.[illegible]70 |
| 28 | 32.000 | 107.[illegible]0 | 93.[illegible]0 | 88.253 | 82.[illegible]2[illegible] |
| 29 | 34.000 | [illegible].[illegible]92 | 93.[illegible]1 | 88.193 | 82.[illegible]2 |
| 30 | 36.000 | [illegible].[illegible]73 | 93.331 | 87.[illegible]1 | 82.[illegible]9 |
| 31 | 38.000 | 107.145 | 93.[illegible]7 | 88.127 | 82.[illegible]0 |
| 32 | 40.000 | 107.058 | [illegible] | 88.160 | 82.[illegible]37 |
| 33 | 42.000 | 107.[illegible]3 | 93.[illegible]72 | 88.[illegible]7 | 81.[illegible]0 |
| 34 | 44.000 | 107.7[illegible] | 92.773 | 88.226 | 81.[illegible] |
| 35 | 46.000 | 107.100 | 93.371 | 88.319 | 82.[illegible]53 |
| 36 | 48.000 | 107.1[illegible]4 | 93.333 | 88.2[illegible]5 | 82.389 |
| 37 | 50.000 | [illegible].[illegible]30 | 93.519 | 88.127 | 82.[illegible]6 |
| 38 | 52.000 | 107.912 | 92.[illegible]8 | 88.160 | 81.[illegible]65 |
| 39 | 54.000 | 107.613 | 92.925 | 88.100 | 81.857 |
| 40 | 55.000 | 107.017 | 9[illegible].[illegible]3 | 88.100 | 82.313 |
| 41 | 58.000 | 107.105 | 93.331 | 87.974 | 82.[illegible]97 |
| 42 | 60.000 | 107.227 | 93.250 | 88.039 | 82.[illegible]05 |
| 43 | 62.000 | 107.143 | 93.333 | 88.193 | 82.[illegible]3 |
| 44 | 64.000 | 107.016 | 93.[illegible]4 | 88.193 | 82.[illegible]1 |
| 45 | 65.000 | 107.1[illegible]2 | 93.334 | 88.160 | 82.273 |
| 46 | 68.000 | [illegible].718 | 93.[illegible]55 | 88.132 | 82.574 |
| 47 | 70.000 | 107.059 | 93.[illegible]07 | 88.[illegible]72 | 82.255 |
| 48 | 72.000 | [illegible].075 | 93.7[illegible]3 | 87.913 | 82.[illegible]2 |
| 49 | 74.000 | [illegible].228 | 93.259 | 88.[illegible]11 | 82.[illegible]5 |
| 50 | 76.000 | [illegible].[illegible]21 | 93.956 | 88.[illegible]98 | 82.[illegible]6 |
| 51 | 78.000 | 107.1[illegible]5 | 93.290 | 88.226 | 82.3[illegible]1 |
| 52 | 80.000 | [illegible].[illegible]29 | 93.220 | 88.2[illegible]5 | 82.[illegible]3 |
| 53 | 82.000 | [illegible].883 | 93.5[illegible]6 | 88.132 | 82.[illegible]3 |
| 54 | 84.000 | [illegible].975 | 93.[illegible] | 88.[illegible]5 | 82.350 |
| 55 | 86.000 | [illegible].718 | 93.705 | 88.198 | 82.[illegible]5 |
| 56 | 88.000 | [illegible].[illegible]64 | 93.[illegible]2[illegible] | 88.[illegible]72 | 82.71[illegible] |
| 57 | 90.000 | 107.230 | 93.255 | 88.011 | 82.[illegible]67 |
| 58 | 92.000 | [illegible].[illegible]2[illegible] | 93.957 | 88.[illegible]72 | 82.7[illegible]8 |
| 59 | 94.000 | 100.604 | 93.669 | 88.105 | 82.[illegible]81 |
| 60 | 96.000 | 100.761 | 93.607 | 88.132 | 82.561 |
| 61 | 98.000 | [illegible].761 | 93.[illegible]67 | 88.[illegible]7 | 82.[illegible]3 |
| 62 | 100.000 | 107.059 | 93.[illegible]6 | 88.[illegible]36 | 82.[illegible]4 |
| 63 | 102.000 | 107.015 | 93.[illegible]5 | 87.[illegible]85 | 82.1[illegible]4 |
| 64 | 104.000 | [illegible].077 | 93.[illegible]1 | 88.[illegible]72 | 82.[illegible]9 |
| 65 | 106.000 | [illegible].[illegible]7[illegible] | 93.[illegible]1 | 88.[illegible]2 | 82.[illegible]5 |
| 66 | 108.000 | [illegible].252 | 93.115 | 88.[illegible]5 | 82.[illegible]3 |
| 67 | 110.000 | [illegible].[illegible]3 | 93.[illegible]29 | 88.165 | 82.[illegible]3 |
| 68 | 112.000 | [illegible].591 | 93.816 | 88.319 | 82.[illegible]7 |
| 69 | 114.000 | [illegible].547 | 93.855 | 88.165 | 82.737 |
| 70 | 116.000 | [illegible].717 | 93.7[illegible]6 | 88.132 | 82.575 |
| 71 | 118.000 | 100.845 | 93.594 | 88.258 | 82.598 |

## 1.7.4 TABULATED DATA - TWO HOUR RUN

### 1.7.4.1 Clean Fluid

| Manufacturer | Pump Code No. |
|---|---|
| 1 | 57740 |
| | 12566 |
| | 25331 |
| | 84387 |
| 2 | 56941 |
| | 11458 |
| | 16439 |
| | 05585 |
| 3 | 10281 |
| | 63661 |
| | 17453 |
| | 18103 |

1.7.3.3 Graphical Summary

REPRESENTATIVE GRAPH OF

DIFFERENTIAL PRESSURE VS. TIME

FOR CYCLIC BREAK-IN TEST

This representative profile curve describes the cyclic break-in test. The test was performed immediately after determining the roll-off cleanliness.

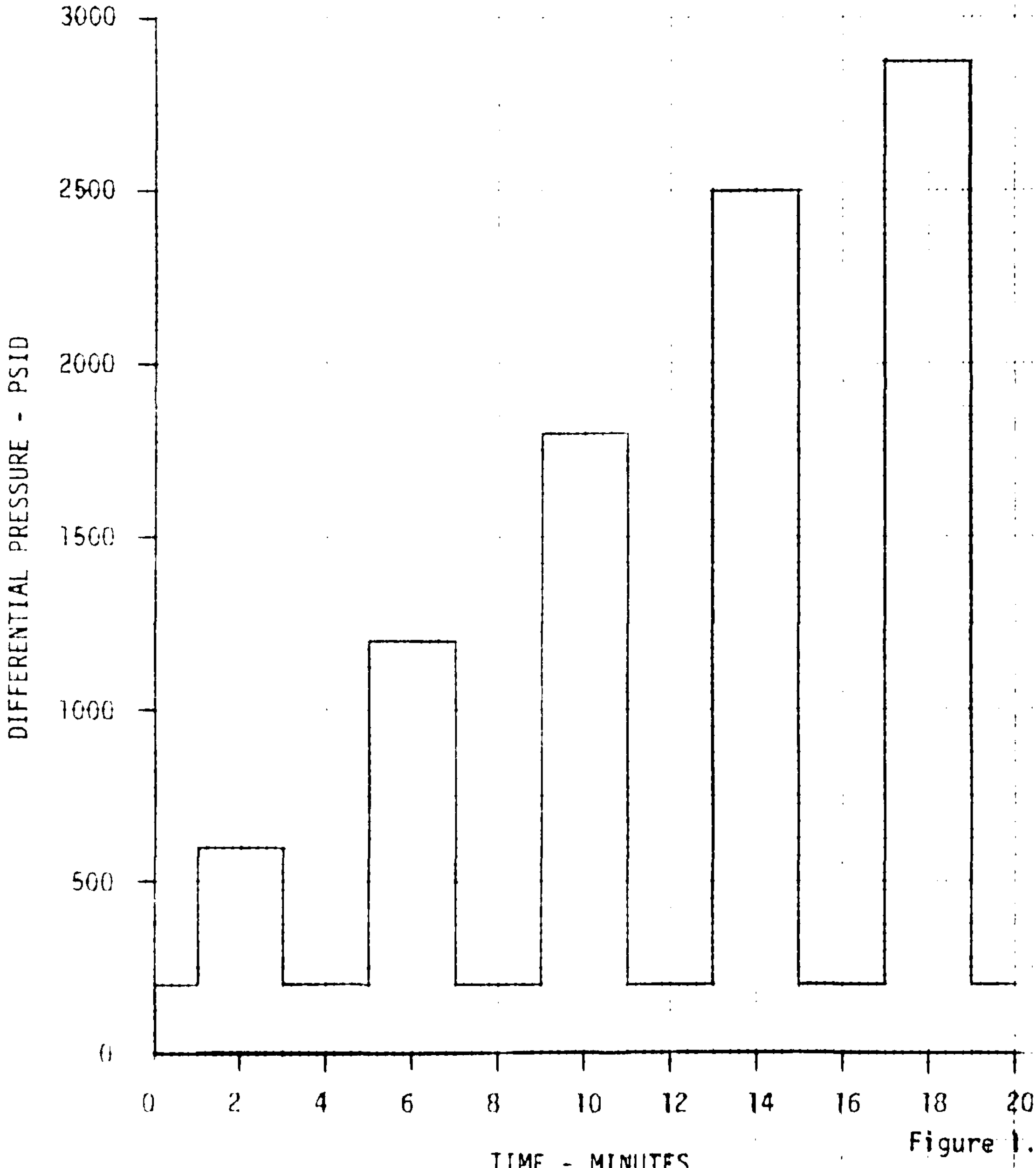



Figure 1.7.1

J.M.
6-21-79

PART 1 ; PUMP CODE NO. 17083 - 120 DEG. F.
SECTION 1.02 ; NORMALIZED VALUES OF CYCLIC BREAKIN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 257.313 | 158.512 | 98.175 | 63.166 | 62.030 |
| 2 | 2.000 | 604.620 | 127.760 | 97.681 | 78.272 | 76.477 |
| 3 | 4.000 | 255.309 | 161.887 | 98.288 | 61.772 | 60.730 |
| 4 | 6.000 | 1206.038 | 113.365 | 96.080 | 89.210 | 84.775 |
| 5 | 8.000 | 255.349 | 153.314 | 98.364 | 65.226 | 64.176 |
| 6 | 10.000 | 1797.309 | 109.649 | 94.778 | 91.200 | 86.460 |
| 7 | 12.000 | 249.324 | 158.619 | 98.384 | 63.048 | 62.045 |
| 8 | 14.000 | 2499.586 | 107.463 | 93.299 | 93.055 | 86.902 |
| 9 | 16.000 | 257.365 | 152.124 | 98.407 | 65.736 | 64.705 |
| 10 | 18.000 | 2878.997 | 106.929 | 92.282 | 93.528 | 86.333 |
| 11 | 20.000 | 255.330 | 164.205 | 98.228 | 60.900 | 59.836 |

PART 1 ; PUMP CODE NO. 0815A - 120 DEG. F.
SECTION 1.02 ; NORMALIZED VALUES OF CYCLIC BREAKIN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 255.478 | 154.168 | 99.107 | 64.864 | 64.233 |
| 2 | 2.000 | 541.102 | 124.811 | 98.312 | 80.121 | 79.704 |
| 3 | 4.000 | 254.484 | 155.547 | 99.140 | 64.289 | 63.645 |
| 4 | 6.000 | 1199.683 | 114.152 | 96.620 | 87.602 | 84.572 |
| 5 | 8.000 | 251.520 | 157.219 | 99.193 | 63.565 | 63.041 |
| 6 | 10.000 | 1793.606 | 111.542 | 95.267 | 89.652 | 85.337 |
| 7 | 12.000 | 248.502 | 162.472 | 99.206 | 61.549 | 61.019 |
| 8 | 14.000 | 2497.249 | 109.509 | 94.095 | 91.317 | 85.854 |
| 9 | 16.000 | 248.552 | 162.440 | 99.243 | 61.561 | 61.057 |
| 10 | 18.000 | 2870.153 | 109.465 | 93.802 | 91.354 | 85.692 |
| 11 | 20.000 | 246.531 | 165.374 | 99.229 | 60.469 | 59.954 |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 : PUMP CODE NO. 44947 - 120 DEG. F
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 208.597 | 154.115 | 97.179 | 62.848 | 61.076 |
| 2 | 2.000 | 574.187 | 122.677 | 95.528 | 81.515 | 77.871 |
| 3 | 4.000 | 208.633 | 159.087 | 97.160 | 62.859 | 61.075 |
| 4 | 6.000 | 1203.240 | 113.441 | 93.880 | 88.152 | 82.759 |
| 5 | 8.000 | 205.010 | 167.557 | 97.295 | 59.681 | 58.064 |
| 6 | 10.000 | 1747.078 | 110.666 | 92.625 | 90.362 | 83.700 |
| 7 | 12.000 | 205.651 | 168.545 | 97.274 | 59.331 | 57.716 |
| 8 | 14.000 | 2501.863 | 111.570 | 91.720 | 89.630 | 82.211 |
| 9 | 16.000 | 203.718 | 170.144 | 97.072 | 58.774 | 57.054 |
| 10 | 18.000 | 2873.740 | 110.615 | 90.912 | 90.404 | 82.191 |
| 11 | 20.000 | 200.706 | 173.744 | 96.921 | 57.556 | 55.785 |

PART 1 : PUMP CODE NO. 58678 - 120 DEG. F
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 203.576 | 165.103 | 96.231 | 60.568 | 58.287 |
| 2 | 2.000 | 590.187 | 125.313 | 94.541 | 79.800 | 75.446 |
| 3 | 4.000 | 203.654 | 169.166 | 96.958 | 59.114 | 57.305 |
| 4 | 6.000 | 1194.225 | 115.011 | 92.992 | 86.948 | 80.657 |
| 5 | 8.000 | 201.682 | 171.852 | 96.647 | 58.186 | 56.236 |
| 6 | 10.000 | 1793.064 | 111.985 | 91.855 | 89.295 | 82.024 |
| 7 | 12.000 | 200.694 | 172.708 | 96.659 | 57.901 | 56.084 |
| 8 | 14.000 | 2505.931 | 110.030 | 90.689 | 90.885 | 82.424 |
| 9 | 16.000 | 200.724 | 178.961 | 97.031 | 55.878 | 54.221 |
| 10 | 18.000 | 2878.812 | 109.747 | 90.281 | 91.119 | 82.265 |
| 11 | 20.000 | 201.713 | 184.332 | 97.129 | 54.250 | 52.694 |

PART 1 : PUMP CODE NO. 18593 - 120 DEG. F
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 197.442 | 141.247 | 95.283 | 70.778 | 67.473 |
| 2 | 2.000 | 613.571 | 116.565 | 89.304 | 85.790 | 76.631 |
| 3 | 4.000 | 194.544 | 136.578 | 94.586 | 73.218 | 69.269 |
| 4 | 6.000 | 1205.981 | 114.058 | 80.984 | 87.675 | 71.018 |
| 5 | 8.000 | 190.636 | 149.746 | 94.461 | 66.780 | 63.094 |
| 6 | 10.000 | 1784.309 | 115.624 | 75.417 | 86.484 | 65.237 |
| 7 | 12.000 | 189.683 | 155.128 | 94.319 | 64.463 | 60.813 |
| 8 | 14.000 | 2543.426 | 115.509 | 67.002 | 86.574 | 58.018 |
| 9 | 16.000 | 187.626 | 159.170 | 94.258 | 62.826 | 59.231 |
| 10 | 18.000 | 2886.000 | 113.463 | 91.456 | 87.748 | 80.267 |
| 11 | 20.000 | 190.622 | 161.939 | 97.019 | 61.752 | 59.923 |

PART 1 : PUMP CODE NO. 68952 - 120 DEG. F
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 204.744 | 165.505 | 99.427 | 60.421 | 60.088 |
| 2 | 2.000 | 603.185 | 125.464 | 98.078 | 79.704 | 78.906 |
| 3 | 4.000 | 194.775 | 168.509 | 99.306 | 59.344 | 58.968 |
| 4 | 6.000 | 1193.224 | 115.633 | 97.068 | 85.741 | 84.017 |
| 5 | 8.000 | 197.811 | 172.408 | 99.371 | 58.002 | 57.647 |
| 6 | 10.000 | 1662.045 | 111.734 | 96.962 | 89.498 | 86.798 |
| 7 | 12.000 | 195.821 | 171.913 | 99.400 | 58.169 | 57.856 |
| 8 | 14.000 | 2516.890 | 108.497 | 94.899 | 91.810 | 87.165 |
| 9 | 16.000 | 194.849 | 172.770 | 99.428 | 57.881 | 57.562 |
| 10 | 18.000 | 2663.824 | 109.330 | 93.451 | 91.486 | 85.494 |
| 11 | 20.000 | 193.908 | 172.474 | 99.252 | 57.980 | 57.559 |

### 1.7.3 TABULATED DATA - CYCLIC BREAK-IN

#### 1.7.3.2 Contaminated Fluid

| Manufacturer | Pump Code No. |
|---|---|
| 1 | 44947 |
| | 58678 |
| 2 | 18593 |
| | 64952 |
| 3 | 17983 |
| | 08158 |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 : PUMP CODE NO. 10281 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT | |
|---|---|---|---|---|---|---|---|
| 1 | 0.000 | 241.606 | 129.945 | 98.014 | 76.979 | 75.389 | |
| 2 | 2.000 | 604.496 | 113.374 | 95.603 | 88.203 | 84.256 | |
| 3 | 4.000 | 244.608 | 127.547 | 97.748 | 78.002 | 76.574 | |
| 4 | 6.000 | 1207.713 | 108.932 | 92.475 | 91.800 | 84.523 | |
| 5 | 8.000 | 240.808 | 129.606 | 97.734 | 77.121 | 75.312 | |
| 6 | 10.000 | 1786.732 | 107.743 | 90.952 | 92.014 | 84.547 | |
| 7 | 12.000 | 230.852 | 130.278 | 97.694 | 73.379 | 71.629 | |
| 8 | 14.000 | 2491.721 | 107.649 | 89.938 | 92.902 | 83.446 | |
| 9 | 16.000 | 231.452 | 140.567 | 100.351 | 71.141 | 71.332 | Note 3 |
| 10 | 18.000 | 2607.778 | 108.753 | 89.371 | 91.952 | 82.111 | |
| 11 | 20.000 | 230.832 | 142.879 | 97.754 | 69.989 | 68.361 | |

PART 1 : PUMP CODE NO. 63661 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 330.452 | 148.066 | 96.772 | 67.546 | 65.312 |
| 2 | 2.000 | 666.674 | 126.251 | 96.465 | 77.972 | 75.155 |
| 3 | 4.000 | 320.526 | 148.927 | 96.677 | 67.147 | 64.862 |
| 4 | 6.000 | 1211.120 | 116.314 | 94.126 | 85.974 | 80.950 |
| 5 | 8.000 | 313.590 | 149.694 | 96.478 | 66.803 | 64.377 |
| 6 | 10.000 | 1789.333 | 112.799 | 92.376 | 86.728 | 81.896 |
| 7 | 12.000 | 312.666 | 152.701 | 96.605 | 65.488 | 63.212 |
| 8 | 14.000 | 2500.561 | 112.418 | 90.553 | 88.954 | 80.466 |
| 9 | 16.000 | 311.610 | 153.824 | 96.482 | 65.009 | 62.671 |
| 10 | 18.000 | 2852.677 | 113.107 | 89.664 | 88.412 | 79.185 |
| 11 | 20.000 | 311.604 | 158.271 | 96.698 | 63.183 | 61.047 |

PART 1 : PUMP CODE NO. 17453 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 240.624 | 157.160 | 97.653 | 63.629 | 62.025 |
| 2 | 2.000 | 595.530 | 124.462 | 95.797 | 80.346 | 76.989 |
| 3 | 4.000 | 238.262 | 161.056 | 97.319 | 62.079 | 60.412 |
| 4 | 6.000 | 1203.823 | 113.563 | 93.253 | 88.057 | 82.138 |
| 5 | 8.000 | 242.620 | 159.263 | 97.424 | 62.789 | 61.189 |
| 6 | 10.000 | 1775.946 | 110.155 | 91.447 | 90.756 | 83.015 |
| 7 | 12.000 | 241.655 | 164.724 | 97.410 | 60.684 | 59.128 |
| 8 | 14.000 | 2502.127 | 107.657 | 89.236 | 92.479 | 82.903 |
| 9 | 16.000 | 236.657 | 167.432 | 97.389 | 59.726 | 58.182 |
| 10 | 18.000 | 2823.196 | 108.564 | 88.384 | 92.111 | 81.434 |
| 11 | 20.000 | 233.645 | 169.591 | 97.337 | 58.966 | 57.410 |

PART 1 : PUMP CODE NO. 18103 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 255.157 | 126.673 | 97.596 | 79.119 | 77.432 |
| 2 | 2.000 | 592.422 | 110.855 | 96.314 | 90.208 | 86.906 |
| 3 | 4.000 | 239.170 | 123.424 | 98.080 | 80.975 | 79.766 |
| 4 | 6.000 | 1197.747 | 105.101 | 94.045 | 95.145 | 89.501 |
| 5 | 8.000 | 249.205 | 120.479 | 97.836 | 83.062 | 81.228 |
| 6 | 10.000 | 1743.883 | 100.074 | 94.029 | 96.082 | 88.561 |
| 7 | 12.000 | 241.152 | 124.092 | 94.814 | 87.545 | 78.864 |
| 8 | 14.000 | 2496.875 | 105.013 | 95.476 | 94.455 | 90.597 |
| 9 | 16.000 | 246.230 | 137.507 | 97.735 | 78.027 | 76.671 |
| 10 | 18.000 | 2835.340 | 104.322 | 89.319 | 95.857 | 85.641 |
| 11 | 20.000 | 247.250 | 125.374 | 97.878 | 79.762 | 78.090 |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 : PUMP CODE NO. 56041 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 192.439 | 151.073 | 99.256 | 66.193 | 65.715 |
| 2 | 2.000 | 596.347 | 119.541 | 96.401 | 83.653 | 82.334 |
| 3 | 4.000 | 189.455 | 152.290 | 99.240 | 65.664 | 65.179 |
| 4 | 6.000 | 1206.450 | 110.650 | 97.022 | 90.375 | 87.703 |
| 5 | 8.000 | 188.461 | 155.430 | 99.293 | 64.338 | 63.253 |
| 6 | 10.000 | 1793.497 | 108.125 | 96.142 | 92.486 | 88.937 |
| 7 | 12.000 | 184.496 | 159.965 | 99.270 | 62.514 | 62.071 |
| 8 | 14.000 | 2494.223 | 107.392 | 94.593 | 93.117 | 88.101 |
| 9 | 16.000 | 186.523 | 160.587 | 99.265 | 62.272 | 61.827 |
| 10 | 18.000 | 2659.606 | 106.339 | 93.025 | 94.039 | 87.499 |
| 11 | 20.000 | 184.526 | 163.519 | 98.967 | 61.155 | 60.536 |

PART 1 : PUMP CODE NO. 11458 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 201.662 | 163.985 | 99.440 | 60.981 | 60.653 |
| 2 | 2.000 | 598.206 | 118.168 | 98.448 | 84.625 | 83.330 |
| 3 | 4.000 | 201.669 | 160.699 | 99.576 | 62.228 | 61.978 |
| 4 | 6.000 | 1202.280 | 111.515 | 97.031 | 89.674 | 87.031 |
| 5 | 8.000 | 203.706 | 152.599 | 99.309 | 65.531 | 65.151 |
| 6 | 10.000 | 1796.059 | 109.522 | 95.811 | 91.256 | 87.452 |
| 7 | 12.000 | 200.716 | 153.774 | 99.448 | 65.031 | 64.686 |
| 8 | 14.000 | 2484.899 | 107.963 | 94.565 | 92.624 | 87.609 |
| 9 | 16.000 | 201.705 | 137.718 | 99.490 | 72.612 | 72.257 |
| 10 | 18.000 | 2897.802 | 108.265 | 92.445 | 92.366 | 85.406 |
| 11 | 20.000 | 201.722 | 150.821 | 99.211 | 66.304 | 65.795 |

PART 1 : PUMP CODE NO. 16439 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 187.586 | 189.500 | 99.380 | 52.770 | 52.454 |
| 2 | 2.000 | 607.673 | 130.867 | 98.423 | 76.414 | 75.225 |
| 3 | 4.000 | 188.627 | 186.113 | 99.403 | 53.731 | 53.422 |
| 4 | 6.000 | 1209.245 | 118.264 | 97.063 | 84.557 | 82.091 |
| 5 | 8.000 | 188.550 | 184.920 | 99.260 | 54.077 | 53.589 |
| 6 | 10.000 | 1799.741 | 114.754 | 95.472 | 87.132 | 83.553 |
| 7 | 12.000 | 186.652 | 186.499 | 99.211 | 53.505 | 53.094 |
| 8 | 14.000 | 2491.041 | 112.923 | 94.708 | 88.556 | 83.868 |
| 9 | 16.000 | 184.692 | 188.883 | 99.289 | 52.943 | 52.578 |
| 10 | 18.000 | 2856.721 | 112.599 | 94.295 | 88.811 | 83.762 |
| 11 | 20.000 | 181.679 | 189.585 | 99.195 | 52.747 | 52.334 |

PART 1 : PUMP CODE NO. 05585 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT | |
|---|---|---|---|---|---|---|---|
| 1 | 0.000 | 193.785 | 151.715 | 98.248 | 65.913 | 64.798 | |
| 2 | 2.000 | 596.515 | 123.705 | 97.678 | 80.837 | 79.139 | |
| 3 | 4.000 | 193.667 | 152.097 | 204.622 | 65.747 | 134.563 | Note 2 |
| 4 | 6.000 | [illegible] | 115.138 | [illegible] | 86.837 | 84.065 | |
| 5 | 8.000 | [illegible] | 149.823 | [illegible] | 66.746 | 65.753 | |
| 6 | 10.000 | 1787.271 | 112.563 | [illegible] | 88.698 | 85.273 | |
| 7 | 12.000 | 192.874 | 151.723 | 97.303 | 65.919 | 63.948 | |
| 8 | 14.000 | 2421.131 | 114.550 | 94.311 | 87.208 | 82.349 | |
| 9 | 16.000 | 189.777 | 151.993 | 98.507 | 65.841 | 64.872 | |
| 10 | 18.000 | 2840.194 | 109.692 | 93.487 | 91.164 | 85.245 | |
| 11 | 20.000 | 188.844 | 152.631 | 98.331 | 65.518 | 64.438 | |

PART 1 : PUMP CODE NO. 57740 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 205.637 | 161.006 | 96.499 | 62.110 | 59.936 |
| 2 | 2.000 | 592.099 | 123.879 | 94.695 | 80.724 | 76.444 |
| 3 | 4.000 | 201.603 | 167.145 | 96.044 | 59.757 | 57.394 |
| 4 | 6.000 | 1203.965 | 113.620 | 92.402 | 88.013 | 81.328 |
| 5 | 8.000 | 196.675 | 167.702 | 95.832 | 59.629 | 57.146 |
| 6 | 10.000 | 1786.651 | 111.154 | 90.706 | 89.965 | 81.606 |
| 7 | 12.000 | 196.663 | 173.680 | 95.755 | 57.577 | 55.134 |
| 8 | 14.000 | 2490.272 | 109.850 | 89.468 | 91.033 | 81.448 |
| 9 | 16.000 | 196.680 | 175.796 | 95.654 | 56.884 | 54.413 |
| 10 | 18.000 | 2661.115 | 114.501 | 88.488 | 87.335 | 77.283 |
| 11 | 20.000 | 195.713 | 175.594 | 95.762 | 56.950 | 54.538 |

PART 1 : PUMP CODE NO. 12566 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 185.855 | 160.193 | 94.404 | 62.429 | 58.937 |
| 2 | 2.000 | 593.337 | 122.966 | 92.722 | 81.324 | 75.407 |
| 3 | 4.000 | 182.891 | 169.657 | 93.410 | 58.943 | 55.060 |
| 4 | 6.000 | 1207.494 | 112.257 | 90.697 | 89.058 | 80.775 |
| 5 | 8.000 | 180.869 | 169.235 | 93.048 | 59.090 | 54.993 |
| 6 | 10.000 | 1801.546 | 109.341 | 88.966 | 91.457 | 81.367 |
| 7 | 12.000 | 176.875 | 173.465 | 92.765 | 57.648 | 53.479 |
| 8 | 14.000 | 2505.555 | 106.691 | 87.433 | 93.729 | 81.952 |
| 9 | 16.000 | 175.874 | 173.468 | 92.713 | 57.648 | 53.448 |
| 10 | 18.000 | 2686.569 | 106.108 | 86.942 | 94.244 | 81.939 |
| 11 | 20.000 | 178.899 | 181.646 | 92.904 | 55.052 | 51.147 |

PART 1 : PUMP CODE NO. 25331 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 205.577 | 151.572 | 97.833 | 61.854 | 60.515 |
| 2 | 2.000 | 606.670 | 131.251 | 96.693 | 82.467 | 79.741 |
| 3 | 4.000 | 204.618 | 162.429 | 97.791 | 61.565 | 60.207 |
| 4 | 6.000 | 1227.635 | [illegible] | 95.211 | 89.752 | 85.451 |
| 5 | 8.000 | [illegible] | [illegible] | 97.816 | 61.355 | 60.023 |
| 6 | 10.000 | 1791.232 | 109.167 | 93.541 | 91.603 | 85.688 |
| 7 | 12.000 | 203.618 | 163.227 | 97.750 | 61.264 | 59.987 |
| 8 | 14.000 | 2489.651 | 107.565 | 91.572 | 92.957 | 85.135 |
| 9 | 16.000 | 203.643 | 166.287 | 97.900 | 60.137 | 58.815 |
| 10 | 18.000 | 2862.397 | 107.057 | 90.578 | 93.408 | 84.610 |
| 11 | 20.000 | 204.648 | 167.513 | 97.798 | 59.697 | 58.384 |

PART 1 : PUMP CODE NO. 84378 - 120 DEG. F.
SECTION 1.02 : NORMALIZED VALUES OF CYCLIC BREAKIN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | DIFF. PRESSURE IN PSID | % OF IDEAL TORQUE | VOL. EFF. IN PERCENT | MECH. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT | |
|---|---|---|---|---|---|---|---|
| 1 | 0.000 | 231.623 | 151.489 | 95.615 | 65.437 | 62.952 | Note 1 |
| 2 | 2.000 | 536.000 | [illegible] | 94.113 | 125.529 | 118.142 | |
| 3 | 4.000 | [illegible] | 152.854 | 95.775 | 65.432 | 62.673 | |
| 4 | 6.000 | [illegible] | 111.723 | 93.104 | 89.523 | 83.457 | |
| 5 | 8.000 | [illegible] | 149.840 | 96.119 | 62.861 | 60.423 | |
| 6 | 10.000 | [illegible] | [illegible] | 92.790 | 91.163 | 82.769 | |
| 7 | 12.000 | 194.651 | [illegible] | 96.112 | 62.306 | 59.885 | |
| 8 | 14.000 | [illegible] | 106.543 | 89.391 | 92.129 | 82.265 | |
| 9 | 16.000 | 194.685 | [illegible] | 95.903 | 60.108 | 57.671 | |
| 10 | 18.000 | [illegible] | 108.193 | 88.557 | 92.427 | 81.852 | |
| 11 | 20.000 | 197.717 | 170.804 | 96.190 | 58.547 | 56.317 | |

## 1.7.3 TABULATED DATA - CYCLIC BREAK-IN

### 1.7.3.1 Clean Fluid

| Manufacturer | Pump Code No. |
|---|---|
| 1 | 57440 |
| | 12566 |
| | 25331 |
| | 84378 |
| 2 | 56941 |
| | 11458 |
| | 16439 |
| | 05585 |
| 3 | 10281 |
| | 63661 |
| | 17453 |
| | 18103 |

Note 1: Mechanical and overall efficienies > 100% due to input torque measurement error. Data should be ignored.

Note 2: Volumetric and overall efficiencies > 100% due to outlet flow measurement error. Data should be ignored.

Note 3: Volumetric efficiency > 100% due to outlet flow measurement error. Data should be ignored.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 : PUMP CODE NO. 10281 - 120 DEG. F.
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | [illegible] | [illegible] | [illegible] | 91.590 | [illegible] |
| 13 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 14 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 17 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 19 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 20 | [illegible] | [illegible] | [illegible] | 91.477 | [illegible] |
| 21 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 22 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 24 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 25 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 26 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 27 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 29 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 31 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 32 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 33 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 34 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 35 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 36 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 39 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 40 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 41 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 42 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 43 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 44 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 45 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 46 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 47 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 49 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 50 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 51 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 52 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 53 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 54 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 55 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 56 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 57 | [illegible] | [illegible] | [illegible] | 91.140 | [illegible] |
| 58 | [illegible] | [illegible] | [illegible] | 91.160 | [illegible] |
| 59 | [illegible] | [illegible] | [illegible] | 91.367 | [illegible] |
| 60 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 61 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 63 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 64 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 65 | [illegible] | [illegible] | 97.173 | [illegible] | [illegible] |
| 66 | [illegible] | 103.150 | [illegible] | [illegible] | [illegible] |
| 67 | [illegible] | 103.211 | [illegible] | [illegible] | [illegible] |
| 68 | [illegible] | 103.313 | [illegible] | 91.193 | [illegible] |
| 69 | [illegible] | 103.396 | 96.710 | 91.006 | [illegible] |
| 70 | [illegible] | [illegible] | 99.351 | [illegible] | 90.479 |

PART 1 : PUMP CODE NO. 63661 - 120 DEG. F.
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | [illegible] | [illegible] | [illegible] | 91.551 | [illegible] |
| 13 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 14 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 17 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 19 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 20 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 21 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 22 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 24 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 25 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 26 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 27 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 29 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 31 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 32 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 33 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 34 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 35 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 36 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 39 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 40 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 41 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 42 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 43 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 44 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 45 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 46 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 47 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 49 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 50 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 51 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 52 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 53 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 54 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 55 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 56 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 57 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 59 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 60 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 61 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 63 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 64 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 65 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 66 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 67 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 68 | 112.000 | [illegible] | [illegible] | [illegible] | 82.333 |
| 69 | 114.000 | 111.937 | 89.336 | [illegible] | 81.626 |

1.7.4 TABULATED DATA - TWO HOUR RUN

1.7.4.2 Contaminated Fluid

| Manufacturer | Pump Code No. |
|---|---|
| 1 | 44947 |
| | 58687 |
| 2 | 18593 |
| | 64952 |
| 3 | 17983 |
| | 08158 |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 ; PUMP CODE NO. 88947 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 13 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 14 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 17 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 19 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 20 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 21 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 22 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 24 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 25 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 26 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 27 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 29 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 31 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 32 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 33 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 34 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 35 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 36 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 39 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 40 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 41 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 42 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 43 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 44 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 45 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 46 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 47 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 49 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 50 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 51 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 52 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 53 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 54 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 55 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 56 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 57 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 59 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 60 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 61 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 63 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 64 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 65 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 66 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 67 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 68 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 69 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 70 | [illegible] | [illegible] | 90.294 | [illegible] | [illegible] |
| 71 | [illegible] | 110.665 | 90.363 | 92.155 | 83.563 |
| 72 | 120.000 | 111.225 | 89.908 | 92.096 | 82.791 |

PART 1 ; PUMP CODE NO. 58678 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 13 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 14 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 17 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 19 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 20 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 21 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 22 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 24 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 25 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 26 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 27 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 29 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 31 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 32 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 33 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 34 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 35 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 36 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 39 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 40 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 41 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 42 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 43 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 44 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 45 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 46 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 47 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 49 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 50 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 51 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 52 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 53 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 54 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 55 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 56 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 57 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 59 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 60 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 61 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 63 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 64 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 65 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 66 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 67 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 68 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 69 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 70 | [illegible] | 110.653 | 90.530 | 90.512 | [illegible] |
| 71 | 118.000 | 110.582 | 90.431 | [illegible] | 81.755 |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 : PUMP CODE NO. 08158 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | 0.000 | 110.965 | 90.167 | 94.754 | 85.372 |
| 13 | 2.000 | 110.552 | 90.455 | 94.634 | 85.335 |
| 14 | 4.000 | 111.012 | 90.260 | 94.569 | 85.213 |
| 15 | 6.000 | 110.823 | 90.234 | 94.652 | 85.363 |
| 16 | 8.000 | 110.674 | 90.192 | 94.588 | 85.206 |
| 17 | 10.000 | 111.177 | 89.947 | 94.579 | 85.015 |
| 18 | 12.000 | 111.142 | 89.475 | 94.562 | 85.017 |
| 19 | 14.000 | 111.711 | 89.517 | 94.440 | 84.475 |
| 20 | 16.000 | 111.366 | 89.794 | 94.545 | 84.431 |
| 21 | 18.000 | 111.400 | 89.700 | 94.545 | 84.405 |
| 22 | 20.000 | 111.245 | 89.459 | 94.545 | 84.442 |
| 23 | 22.000 | 111.526 | 89.655 | 94.545 | 84.709 |
| 24 | 24.000 | 111.734 | 89.140 | 94.355 | 84.332 |
| 25 | 26.000 | 111.558 | 89.500 | 94.512 | 84.579 |
| 26 | 28.000 | 112.333 | 89.021 | 92.265 | 82.072 |
| 27 | 30.000 | 111.671 | 89.354 | 94.512 | 84.418 |
| 28 | 32.000 | 111.409 | 89.759 | 94.373 | 84.465 |
| 29 | 34.000 | 112.357 | 89.004 | 94.325 | 83.777 |
| 30 | 36.000 | 111.949 | 89.205 | 94.373 | 84.295 |
| 31 | 38.000 | 111.903 | 89.351 | 94.460 | 84.317 |
| 32 | 40.000 | 112.649 | 89.172 | 93.988 | 83.571 |
| 33 | 42.000 | 112.078 | 89.224 | 93.471 | 83.780 |
| 34 | 44.000 | 111.846 | 89.375 | 94.145 | 84.077 |
| 35 | 46.000 | 112.462 | 89.232 | 94.267 | 84.070 |
| 36 | 48.000 | 111.962 | 89.310 | 94.058 | 83.744 |
| 37 | 50.000 | 111.633 | 89.724 | 94.006 | 84.261 |
| 38 | 52.000 | 111.527 | 89.424 | 94.111 | 84.193 |
| 39 | 54.000 | 112.192 | 89.214 | 94.401 | 83.924 |
| 40 | 56.000 | 112.432 | 88.943 | 94.111 | [illegible] |
| 41 | 58.000 | 111.995 | 89.237 | 94.076 | 83.733 |
| 42 | 60.000 | 112.335 | 89.017 | 94.076 | 83.579 |
| 43 | 62.000 | 112.227 | 89.264 | 94.163 | 83.389 |
| 44 | 64.000 | 112.337 | 89.115 | 94.128 | 83.726 |
| 45 | 66.000 | 111.940 | 89.334 | 93.989 | 83.804 |
| 46 | 68.000 | 112.402 | 88.919 | 94.146 | 83.659 |
| 47 | 70.000 | 112.537 | 89.200 | 93.972 | 83.811 |
| 48 | 72.000 | [illegible] | 89.235 | 94.129 | 83.931 |
| 49 | 74.000 | 112.742 | [illegible] | 93.937 | [illegible] |
| 50 | 76.000 | 112.057 | 88.735 | 94.098 | [illegible] |
| 51 | 78.000 | [illegible] | 88.439 | 94.094 | 83.528 |
| 52 | 80.000 | [illegible] | 89.247 | [illegible] | [illegible] |
| 53 | 82.000 | 113.474 | 88.120 | 94.163 | 82.919 |
| 54 | 84.000 | 112.721 | 88.714 | 94.129 | [illegible] |
| 55 | 86.000 | [illegible] | 88.435 | 94.111 | 83.152 |
| 56 | 88.000 | 113.211 | 88.431 | 94.198 | [illegible] |
| 57 | 90.000 | 112.935 | 88.560 | 94.111 | 83.267 |
| 58 | 92.000 | 112.341 | 89.014 | 94.153 | 83.754 |
| 59 | 94.000 | [illegible] | 88.290 | 94.161 | [illegible] |
| 60 | 96.000 | 112.592 | 88.816 | 94.275 | 83.575 |
| 61 | 98.000 | 112.687 | 88.741 | 94.110 | [illegible] |
| 62 | 100.000 | [illegible] | [illegible] | 94.075 | 83.185 |
| 63 | 102.000 | 113.173 | 88.435 | 94.058 | 83.119 |
| 64 | 104.000 | 112.762 | 88.642 | 94.075 | 83.364 |
| 65 | 106.000 | 112.637 | 88.761 | 94.075 | 83.457 |
| 66 | 108.000 | 112.537 | [illegible] | 94.162 | [illegible] |
| 67 | 110.000 | [illegible] | 88.181 | 94.197 | [illegible] |
| 68 | 112.000 | 113.817 | 87.860 | 94.070 | 82.592 |
| 69 | 114.000 | 112.512 | [illegible] | 94.190 | 83.642 |
| 70 | 116.000 | 113.163 | 88.368 | 94.180 | 83.161 |
| 71 | 118.000 | 113.222 | 88.322 | 94.233 | 83.164 |
| 72 | 120.000 | 113.107 | 88.412 | 94.127 | 83.156 |

PART 1 : PUMP CODE NO. 17983 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | 0.000 | 107.949 | 92.402 | 94.823 | 87.857 |
| 13 | 2.000 | 107.643 | 92.839 | 94.704 | [illegible] |
| 14 | 4.000 | [illegible] | 92.555 | 94.583 | [illegible] |
| 15 | 6.000 | [illegible] | 92.530 | 94.547 | [illegible] |
| 16 | 8.000 | 108.243 | [illegible] | 94.655 | 87.347 |
| 17 | 10.000 | [illegible] | [illegible] | 94.495 | [illegible] |
| 18 | 12.000 | 107.027 | 92.555 | 94.626 | 87.533 |
| 19 | 14.000 | [illegible] | [illegible] | [illegible] | 87.104 |
| 20 | 16.000 | [illegible] | [illegible] | 94.461 | [illegible] |
| 21 | 18.000 | [illegible] | 92.713 | [illegible] | 87.765 |
| 22 | 20.000 | [illegible] | 93.118 | 94.373 | 87.727 |
| 23 | 22.000 | [illegible] | 93.672 | [illegible] | 88.563 |
| 24 | 24.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 25 | 26.000 | 106.796 | [illegible] | [illegible] | [illegible] |
| 26 | 28.000 | [illegible] | [illegible] | [illegible] | 88.775 |
| 27 | 30.000 | 106.517 | 93.882 | [illegible] | [illegible] |
| 28 | 32.000 | 106.572 | 93.435 | [illegible] | [illegible] |
| 29 | 34.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 30 | 36.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 31 | 38.000 | 106.177 | 94.152 | [illegible] | 88.915 |
| 32 | 40.000 | [illegible] | 93.748 | 94.391 | 88.538 |
| 33 | 42.000 | [illegible] | [illegible] | [illegible] | 88.925 |
| 34 | 44.000 | [illegible] | 93.753 | 94.355 | 88.515 |
| 35 | 46.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 36 | 48.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 | 50.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 | 52.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 39 | 54.000 | [illegible] | 94.120 | 94.373 | [illegible] |
| 40 | 56.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 41 | 58.000 | [illegible] | [illegible] | 94.335 | [illegible] |
| 42 | 60.000 | 105.263 | [illegible] | [illegible] | [illegible] |
| 43 | 62.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 44 | 64.000 | [illegible] | 94.262 | 94.355 | [illegible] |
| 45 | 66.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 46 | 68.000 | [illegible] | 94.155 | [illegible] | [illegible] |
| 47 | 70.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 | 72.000 | [illegible] | 94.512 | 94.391 | [illegible] |
| 49 | 74.000 | [illegible] | [illegible] | 94.155 | [illegible] |
| 50 | 76.000 | 106.172 | 94.107 | [illegible] | [illegible] |
| 51 | 78.000 | 105.748 | [illegible] | 94.341 | [illegible] |
| 52 | 80.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 53 | 82.000 | 106.114 | 94.234 | 94.339 | [illegible] |
| 54 | 84.000 | [illegible] | 94.330 | [illegible] | [illegible] |
| 55 | 86.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 56 | 88.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 57 | 90.000 | [illegible] | [illegible] | 94.321 | [illegible] |
| 58 | 92.000 | [illegible] | [illegible] | 94.321 | [illegible] |
| 59 | 94.000 | 105.976 | 94.301 | 94.373 | [illegible] |
| 60 | 96.000 | 106.100 | 94.240 | 94.373 | [illegible] |
| 61 | 98.000 | [illegible] | [illegible] | 94.373 | [illegible] |
| 62 | 100.000 | [illegible] | 94.105 | 94.373 | [illegible] |
| 63 | 102.000 | [illegible] | [illegible] | 94.373 | [illegible] |
| 64 | 104.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 65 | 106.000 | [illegible] | [illegible] | 94.321 | [illegible] |
| 66 | 108.000 | [illegible] | 94.171 | [illegible] | [illegible] |
| 67 | 110.000 | 105.451 | 94.383 | 94.263 | [illegible] |
| 68 | 112.000 | 105.623 | 94.097 | 94.373 | [illegible] |
| 69 | 114.000 | 106.552 | 93.831 | 94.373 | [illegible] |
| 70 | 116.000 | 105.059 | 94.644 | 94.321 | 89.319 |
| 71 | 118.000 | 105.983 | 94.355 | 94.411 | 89.130 |
| 72 | 120.000 | 105.659 | 94.684 | 94.409 | 89.602 |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

1 : PUMP CODE NO. 18593 - 120 DEG. F.
TION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | 0.000 | 115.564 | 86.056 | 92.223 | 81.233 |
| 13 | 2.000 | 113.764 | 87.901 | 92.048 | 80.937 |
| 14 | 4.000 | 111.082 | 89.540 | 91.887 | 82.301 |
| 15 | 6.000 | 112.764 | 88.451 | 91.950 | 81.568 |
| 16 | 8.000 | 111.990 | 89.294 | 91.708 | 81.995 |
| 17 | 10.000 | 111.553 | [illegible] | 91.891 | 82.401 |
| 18 | 12.000 | 117.767 | 84.413 | 91.930 | 78.085 |
| 19 | 14.000 | 115.769 | 86.379 | 91.069 | [illegible] |
| 20 | 16.000 | 115.140 | 86.851 | 91.891 | 79.834 |
| 21 | 18.000 | 117.406 | 84.815 | 91.950 | 78.011 |
| 22 | 20.000 | 119.417 | 83.391 | 91.930 | 76.586 |
| 23 | 22.000 | 117.462 | 85.134 | 91.632 | 78.035 |
| 24 | 24.000 | 119.565 | 83.636 | 91.607 | 76.641 |
| 25 | 26.000 | 119.414 | 83.743 | 91.578 | 76.731 |
| 26 | 28.000 | 120.357 | 83.086 | 91.828 | 76.321 |
| 27 | 30.000 | 121.730 | [illegible] | 91.700 | 75.979 |
| 28 | 32.000 | 124.870 | 80.084 | 91.978 | 73.683 |
| 29 | 34.000 | 120.350 | 83.070 | 91.565 | 76.087 |
| 30 | 36.000 | 121.519 | 82.291 | 91.539 | 75.353 |
| 31 | 38.000 | 121.231 | 82.487 | 91.509 | 75.508 |
| 32 | 40.000 | [illegible] | [illegible] | 91.343 | 75.704 |
| 33 | 42.000 | 122.154 | [illegible] | 91.603 | 75.013 |
| 34 | 44.000 | 120.478 | 82.728 | 91.535 | 75.729 |
| 35 | 46.000 | 121.765 | 82.125 | 91.652 | 75.301 |
| 36 | 48.000 | 121.387 | 82.381 | 91.535 | 75.631 |
| 37 | 50.000 | [illegible] | 82.372 | 91.475 | 75.374 |
| 38 | 52.000 | [illegible] | 82.651 | 91.415 | 75.580 |
| 39 | 54.000 | 121.320 | 82.423 | 91.407 | 75.364 |
| 40 | 56.000 | [illegible] | 82.006 | 91.517 | 75.074 |
| 41 | 58.000 | [illegible] | 81.934 | 91.683 | [illegible] |
| 42 | 60.000 | [illegible] | 81.598 | 91.620 | 74.875 |
| 43 | 62.000 | 121.671 | 82.175 | 91.317 | 75.064 |
| 44 | 64.000 | [illegible] | 81.903 | 91.471 | [illegible] |
| 45 | 66.000 | [illegible] | [illegible] | 91.501 | 75.081 |
| 46 | 68.000 | [illegible] | 81.834 | 91.272 | 74.716 |
| 47 | 70.000 | [illegible] | 82.219 | 91.317 | 75.104 |
| 48 | 72.000 | [illegible] | 81.431 | 91.373 | 74.430 |
| 49 | 74.000 | [illegible] | 81.700 | 91.373 | 74.576 |
| 50 | 76.000 | [illegible] | [illegible] | 91.441 | 74.529 |
| 51 | 78.000 | [illegible] | 81.644 | 91.178 | 74.456 |
| 52 | 80.000 | 122.375 | 81.716 | 91.373 | 74.591 |
| 53 | 82.000 | 122.978 | 81.349 | 91.437 | 74.407 |
| 54 | 84.000 | 123.132 | 81.214 | 91.505 | 74.339 |
| 55 | 86.000 | 122.715 | [illegible] | 91.403 | [illegible] |
| 56 | 88.000 | [illegible] | [illegible] | 91.565 | 74.416 |
| 57 | 90.000 | [illegible] | [illegible] | 91.403 | [illegible] |
| 58 | 92.000 | 123.410 | 81.031 | 92.252 | 74.777 |
| 59 | 94.000 | [illegible] | 81.678 | [illegible] | 74.520 |
| 60 | 96.000 | 123.257 | 81.131 | 91.340 | 74.129 |
| 61 | 98.000 | [illegible] | 81.550 | 91.433 | [illegible] |
| 62 | 100.000 | 122.911 | 81.360 | 91.340 | [illegible] |
| 63 | 102.000 | 122.762 | 81.458 | 91.506 | [illegible] |
| 64 | 104.000 | 123.513 | 80.963 | 91.340 | 73.975 |
| 65 | 106.000 | 122.915 | 81.357 | 91.306 | 74.307 |
| 66 | 108.000 | [illegible] | 81.401 | 91.306 | 74.367 |
| 67 | 110.000 | [illegible] | 81.251 | 91.403 | 74.290 |
| 68 | 112.000 | [illegible] | 81.036 | 91.369 | 74.065 |
| 69 | 114.000 | 124.932 | 80.063 | 91.505 | 73.285 |
| 70 | 116.000 | [illegible] | 81.077 | 91.235 | [illegible] |
| 71 | 118.000 | 123.668 | 80.849 | 91.433 | 73.946 |
| 72 | 120.000 | 122.901 | 81.366 | 91.336 | 74.340 |

PART 1 : PUMP CODE NO. 68952 - 120 DEG. F.
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

PROCESSED DATA

| | TIME IN MINUTES | % OF IDEAL TORQUE | MECH. EFF. IN PERCENT | VOL. EFF. IN PERCENT | OVER-ALL EFF. IN PERCENT |
|---|---|---|---|---|---|
| 12 | 0.000 | [illegible] | 91.413 | 94.772 | [illegible] |
| 13 | 2.000 | 110.532 | 90.471 | 95.225 | 85.179 |
| 14 | 4.000 | [illegible] | 91.224 | [illegible] | [illegible] |
| 15 | 6.000 | 109.513 | [illegible] | 95.533 | [illegible] |
| 16 | 8.000 | [illegible] | 91.363 | 95.171 | [illegible] |
| 17 | 10.000 | 109.789 | [illegible] | 95.206 | 85.765 |
| 18 | 12.000 | [illegible] | [illegible] | 95.171 | [illegible] |
| 19 | 14.000 | [illegible] | [illegible] | 95.171 | [illegible] |
| 20 | 16.000 | [illegible] | 91.384 | 95.206 | 87.331 |
| 21 | 18.000 | [illegible] | 91.385 | 95.273 | 85.913 |
| 22 | 20.000 | [illegible] | 92.105 | 95.171 | [illegible] |
| 23 | 22.000 | 109.194 | 91.550 | 95.233 | [illegible] |
| 24 | 24.000 | [illegible] | 91.206 | 95.233 | [illegible] |
| 25 | 26.000 | [illegible] | 91.390 | [illegible] | [illegible] |
| 26 | 28.000 | 109.139 | [illegible] | [illegible] | 87.311 |
| 27 | 30.000 | 108.539 | 92.132 | [illegible] | [illegible] |
| 28 | 32.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 29 | 34.000 | [illegible] | [illegible] | 95.073 | [illegible] |
| 30 | 36.000 | [illegible] | [illegible] | 95.171 | [illegible] |
| 31 | 38.000 | [illegible] | [illegible] | [illegible] | 87.333 |
| 32 | 40.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 33 | 42.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 34 | 44.000 | [illegible] | 92.249 | 95.171 | 87.822 |
| 35 | 46.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 36 | 48.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 | 50.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 | 52.000 | [illegible] | [illegible] | 95.135 | [illegible] |
| 39 | 54.000 | [illegible] | [illegible] | [illegible] | 87.732 |
| 40 | 56.000 | [illegible] | [illegible] | 95.198 | [illegible] |
| 41 | 58.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 42 | 60.000 | [illegible] | 92.372 | [illegible] | [illegible] |
| 43 | 62.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 44 | 64.000 | [illegible] | 92.593 | 95.075 | [illegible] |
| 45 | 66.000 | [illegible] | 92.175 | [illegible] | [illegible] |
| 46 | 68.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 47 | 70.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 | 72.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 49 | 74.000 | 107.713 | [illegible] | [illegible] | [illegible] |
| 50 | 76.000 | [illegible] | 92.352 | [illegible] | [illegible] |
| 51 | 78.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 52 | 80.000 | [illegible] | 92.133 | 95.171 | [illegible] |
| 53 | 82.000 | [illegible] | 92.514 | 95.073 | [illegible] |
| 54 | 84.000 | 107.720 | [illegible] | [illegible] | [illegible] |
| 55 | 86.000 | 107.994 | 92.593 | [illegible] | [illegible] |
| 56 | 88.000 | 107.373 | 93.133 | [illegible] | [illegible] |
| 57 | 90.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 | 92.000 | 108.213 | [illegible] | [illegible] | [illegible] |
| 59 | 94.000 | [illegible] | [illegible] | 95.075 | [illegible] |
| 60 | 96.000 | 107.940 | [illegible] | [illegible] | [illegible] |
| 61 | 98.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | 100.000 | [illegible] | 92.722 | [illegible] | [illegible] |
| 63 | 102.000 | [illegible] | 92.727 | 95.128 | 88.237 |
| 64 | 104.000 | [illegible] | 92.727 | [illegible] | [illegible] |
| 65 | 106.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 66 | 108.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 67 | 110.000 | 107.992 | [illegible] | [illegible] | [illegible] |
| 68 | 112.000 | [illegible] | 92.523 | [illegible] | [illegible] |
| 69 | 114.000 | 108.366 | 92.297 | [illegible] | [illegible] |
| 70 | 116.000 | 107.854 | 93.718 | [illegible] | [illegible] |
| 71 | 118.000 | 107.986 | 92.605 | [illegible] | 87.922 |
| 72 | 120.000 | 107.664 | 92.882 | [illegible] | 88.301 |

1.7.4.3 Tabulated Summary - Two Hour Run

Root-mean-square was adopted because it is a good measure of the degree to which a parameter varies from a desired or target value. For instance looking at the table for manufacturer 1, 67% (RMS of Deviation = One Standard Deviation 67% of all observations) of all pressure readings on pump number 58678 lay within ± 5 psi of an average pressure level of 2498 psi.

The following data was calculated from a sample size of approximately 65 data points for each pump, taken during the steady state two hour break-in run. Values of QAVE, TAVE, and PAVE were arrived at by averaging the 65 data points for each parameter respectively.

Mfgr. 1

RMS VALUES OF DEVIATION FROM AVERAGE

| Pump Code # | RMS (Q-QAVE) (GPM) | RMS (T-TAVE) (in-lbs) | PAVE (PSI) | RMS (P-PAVE) (PSI) | NAVE (RPM) | RMS (N-NAVE) (RPM) |
|---|---|---|---|---|---|---|
| 58678* | .114 | 4 | 2498 | 5 | 2699 | 10 |
| 44947* | .119 | 5 | 2494 | 4 | 2700 | 1 |
| 12566 | .067 | 4 | 2498 | 2 | 2693 | 2 |
| 25331 | .102 | 5 | 2489 | 3 | 2697 | 8 |
| 84378 | .051 | 3 | 2493 | 2 | 2696 | 4 |
| 57740 | .083 | 8 | 2498 | 5 | 2701 | 8 |

AVERAGE VALUES OF EFFICIENCIES

| Pump Code # | Vol. Eff. (%) | Mech. Eff. (%) | Overall Eff. (%) |
|---|---|---|---|
| 58678* | 90.4 | 90.3 | 81.7 |
| 44947* | 91.4 | 90.9 | 83.1 |
| 12566 | 88.1 | 93.5 | 82.3 |
| 25331 | 92 | 92.1 | 84.7 |
| 84378 | 90.1 | 91.7 | 82.6 |
| 57740 | 90.2 | 91.0 | 82.1 |

*Pumps broken in with contaminated fluid.

Mfgr. 2

RMS VALUES OF DEVIATION FROM AVERAGE

| Pump Code # | RMS (Q-QAVE) (GPM) | RMS (T-TAVE) (in-lbs) | PAVE (PSI) | RMS (P-AVE) (PSI) | NAVE (RPM) | RMS (N-NAVE) (RPM) |
|---|---|---|---|---|---|---|
| 05585 | .530 | 12 | 2500 | 1 | 2710 | 49 |
| 11458 | .128 | 48 | 2495 | 14 | 2704 | 11 |
| 16439 | .497 | 11 | 2501 | 2 | 2707 | 50 |
| 56941 | .080 | 12 | 2499 | 8 | 2696 | 5 |
| 18593* | .083 | 37 | 2495 | 18 | 2697 | 5 |
| 64952* | .028 | 8 | 2496 | 9 | 2704 | 1 |

AVERAGE VALUES OF EFFICIENCIES

| Pump Code # | Vol. Eff. (%) | Mech. Eff. (%) | Overall Eff. (%) |
|---|---|---|---|
| 05585 | 93.6 | 93.4 | 87.4 |
| 11458 | 93.5 | 95.3 | 89.1 |
| 16439 | 93.8 | 95.9 | 90.0 |
| 56941 | 91.3 | 96.6 | 90.1 |
| 18593* | 91.6 | 82.8 | 75.9 |
| 64952* | 95.1 | 92.2 | 87.7 |

*Pumps broken in with contaminated fluid.

Mfgr. 3

RMS VALUES OF DEVIATION FROM AVERAGE

| Pump Code # | RMS (Q-QAVE (GPM) | RMS (T-TAVE) (in-lbs) | PAVE (PSI) | RMS (P-AVE) (PSI) | NAVE (RPM) | RMS (N-NAVE) (RPM) |
|---|---|---|---|---|---|---|
| 63661 | .060 | 16 | 2474 | 4 | 2700 | 4 |
| 10281 | .084 | 24 | 2527 | 25 | 2699 | 7 |
| 18103 | .555 | 17 | 2500 | 2 | 2715 | 49 |
| 17453 | .478 | 18 | 2504 | 6 | 2714 | 43 |
| 08158* | .121 | 9 | 2495 | 5 | 2697 | 8 |
| 17983* | .034 | 10 | 2494 | 7 | 2696 | 2 |

AVERAGE VALUES OF EFFICIENCIES

| Pump Code # | Vol. Eff. (%) | Mech. Eff. (%) | Overall Eff. (%) |
|---|---|---|---|
| 63661 | 91.4 | 88.8 | 81.1 |
| 10281 | 91.3 | 94.8 | 86.5 |
| 18103 | 90.6 | 94.1 | 85.3 |
| 17453 | 89.0 | 94.5 | 84.1 |
| 08158* | 94.2 | 89.1 | 83.9 |
| 17983* | 94.4 | 93.9 | 88.7 |

*Pumps broken in with contaminated fluid.

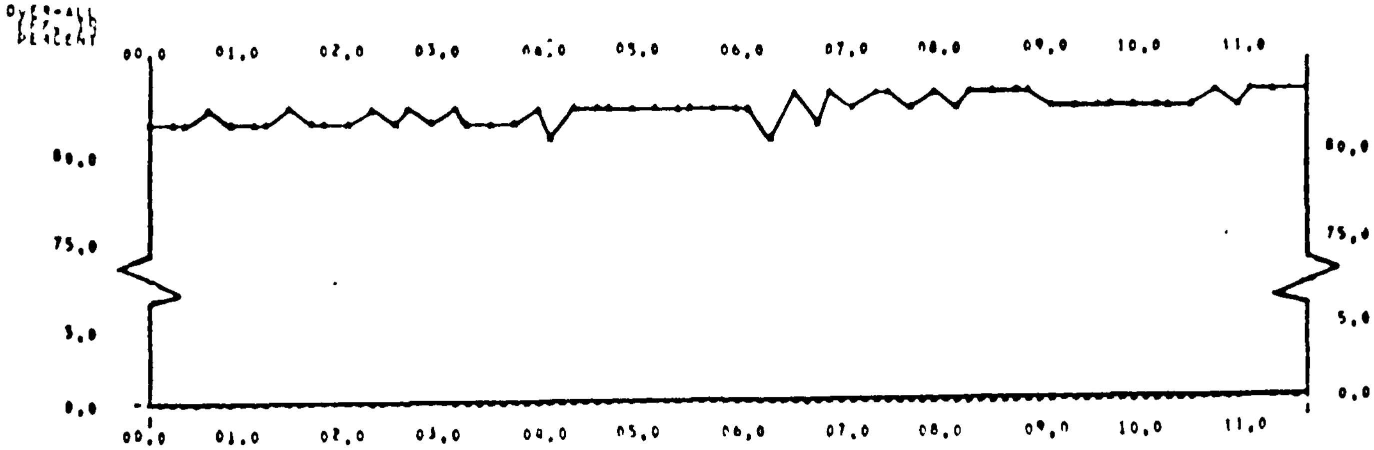
## 1.7.5 GRAPHICAL DATA - TWO HOUR RUN

### 1.7.5.1 Clean Fluid

| Manufacturer | Pump Code No. |
|---|---|
| 1 | 57740 |
| | 12566 |
| | 25331 |
| | 84387 |
| 2 | 56941 |
| | 11458 |
| | 16439 |
| | 05585 |
| 3 | 10281 |
| | 63661 |
| | 17453 |
| | 18103 |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 ; PUMP CODE NO. 57790 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID



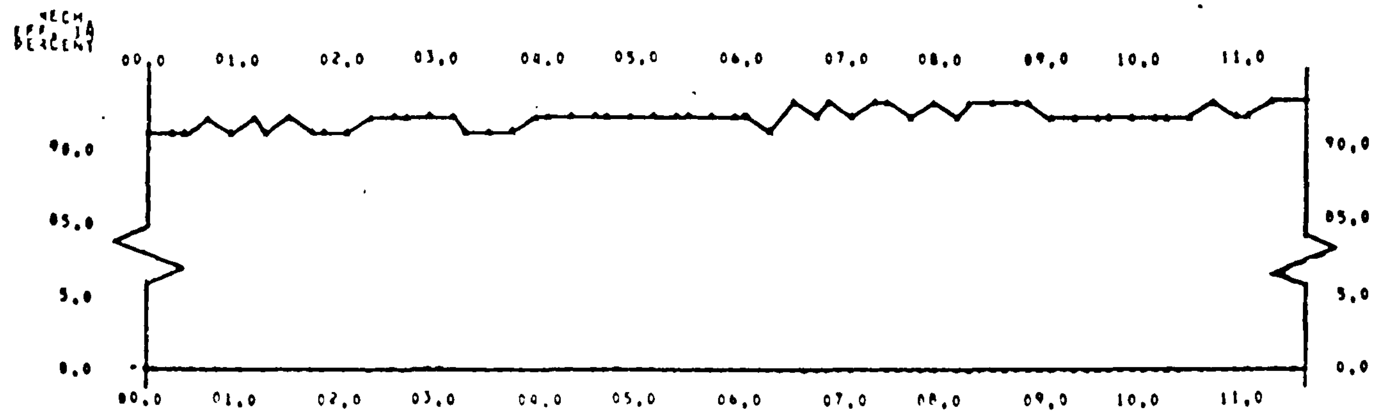

TIME IN MINUTES MULTIPLY BY $10^1$

83,072 IS MAX. OVERALL EFF. IN PERCENT, 80,827 IS MIN.

112,000 IS MAX. TIME IN MINUTES, 0,000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 ; PUMP CODE NO. 57790 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

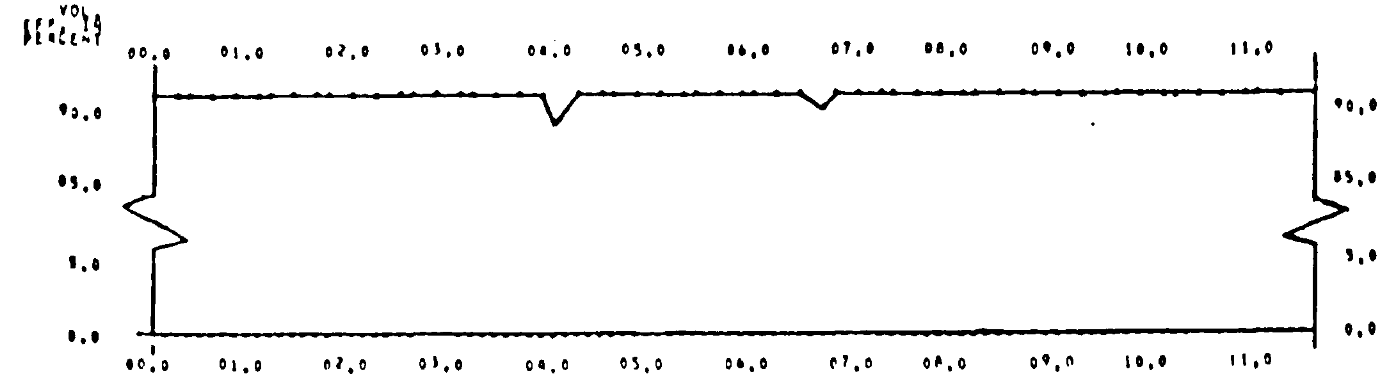



TIME IN MINUTES MULTIPLY BY $10^1$

92,017 IS MAX. MECH. EFF. IN PERCENT, 89,709 IS MIN.

112,000 IS MAX. TIME IN MINUTES, 0,000 IS MIN.

PART 1 ; PUMP CODE NO. 57790 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID



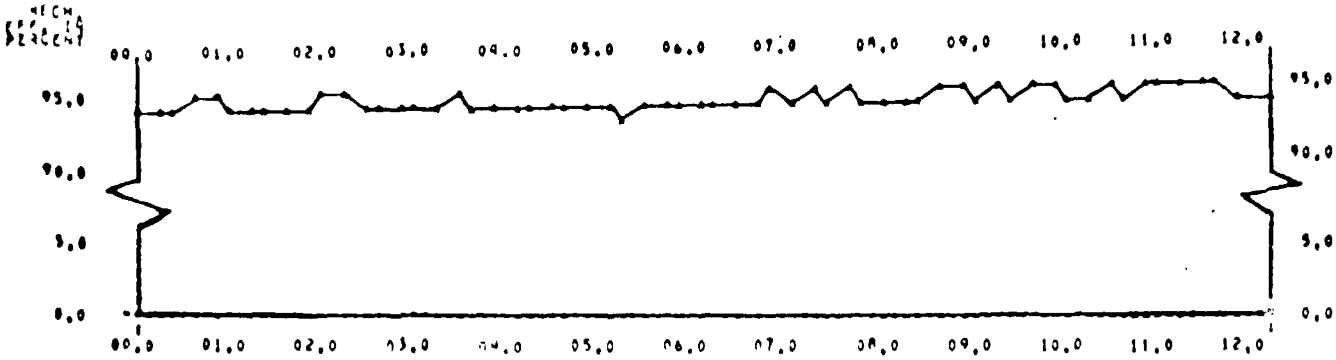

TIME IN MINUTES MULTIPLY BY $10^1$

90,350 IS MAX. VOL. EFF. IN PERCENT, 88,913 IS MIN.

112,000 IS MAX. TIME IN MINUTES, 0,000 IS MIN.

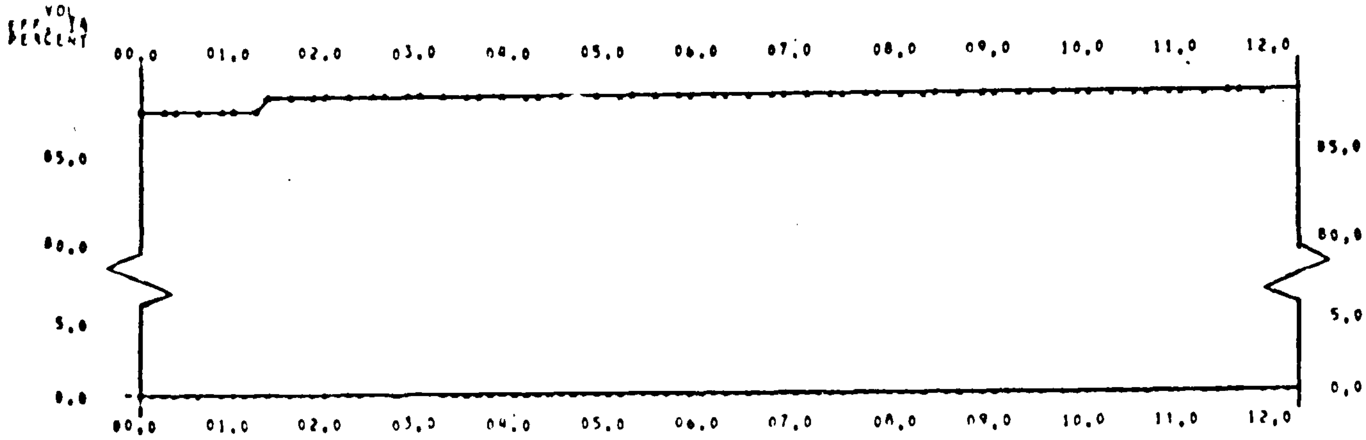
TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 : PUMP CODE NO. 12500 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID



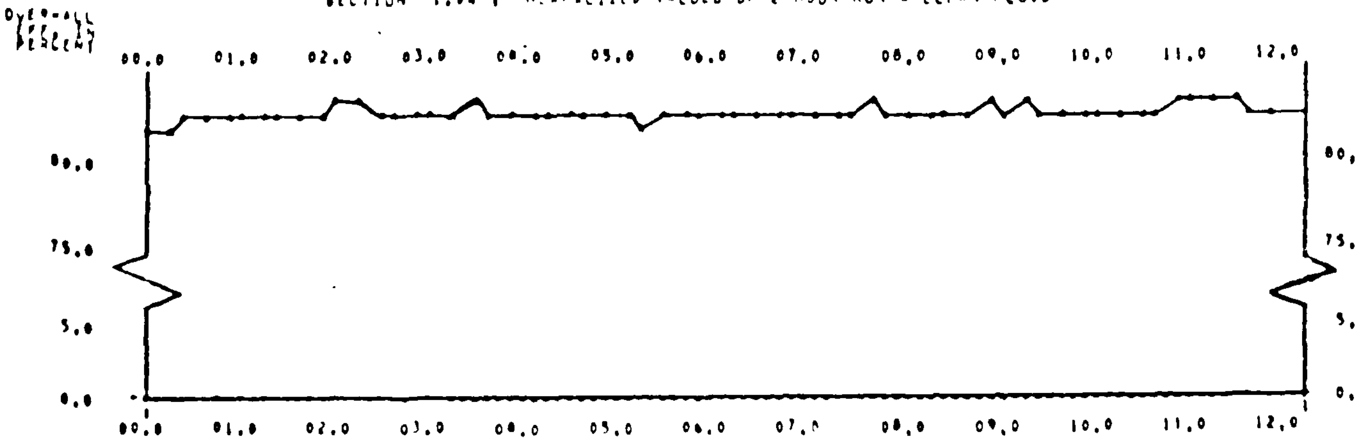

TIME IN MINUTES MULTIPLY BY $10^1$
94,116 IS MAX. MECH. EFF. IN PERCENT, 92,668 IS MIN.
118,000 IS MAX. TIME IN MINUTES. 0,000 IS MIN.

PART 1 : PUMP CODE NO. 12500 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID




TIME IN MINUTES MULTIPLY BY $10^1$
88,319 IS MAX. VOL. EFF. IN PERCENT. 87,318 IS MIN.
118,000 IS MAX. TIME IN MINUTES. 0,000 IS MIN.

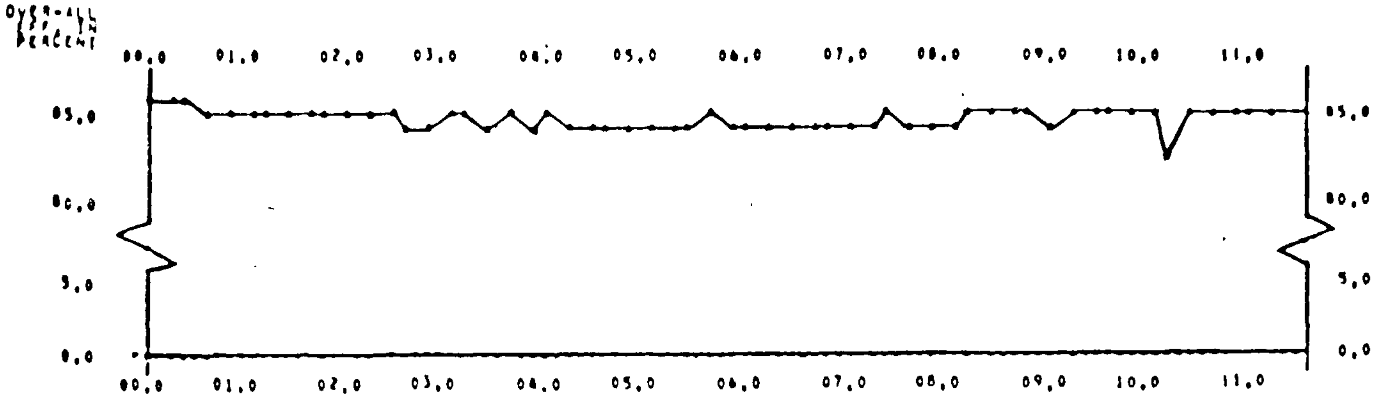
PART 1 : PUMP CODE NO. 12500 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID




TIME IN MINUTES MULTIPLY BY $10^1$
83,060 IS MAX. OVERALL EFF. IN PERCENT. 81,581 IS MIN.
118,000 IS MAX. TIME IN MINUTES. 0,000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 ; PUMP CODE NO. 2333 - 120 DEG. F
SECTION 1.0A ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

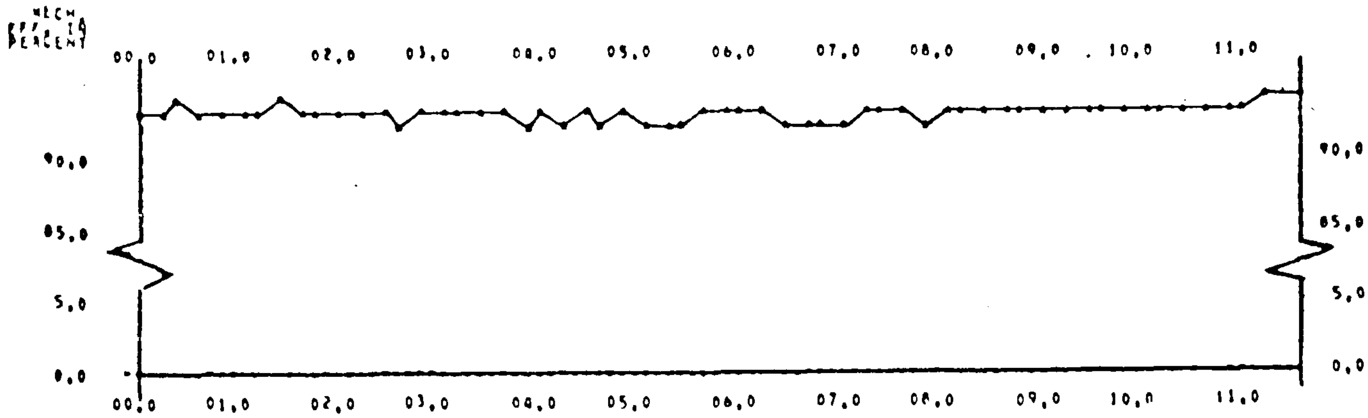



TIME IN MINUTES MULTIPLY BY 10[1]

85.848 IS MAX. OVERALL EFF. IN PERCENT. 82.610 IS MIN.

112.000 IS MAX. TIME IN MINUTES. 0.000 IS MIN.

PART 1 ; PUMP CODE NO. 2333 - 120 DEG. F
SECTION 1.0A ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

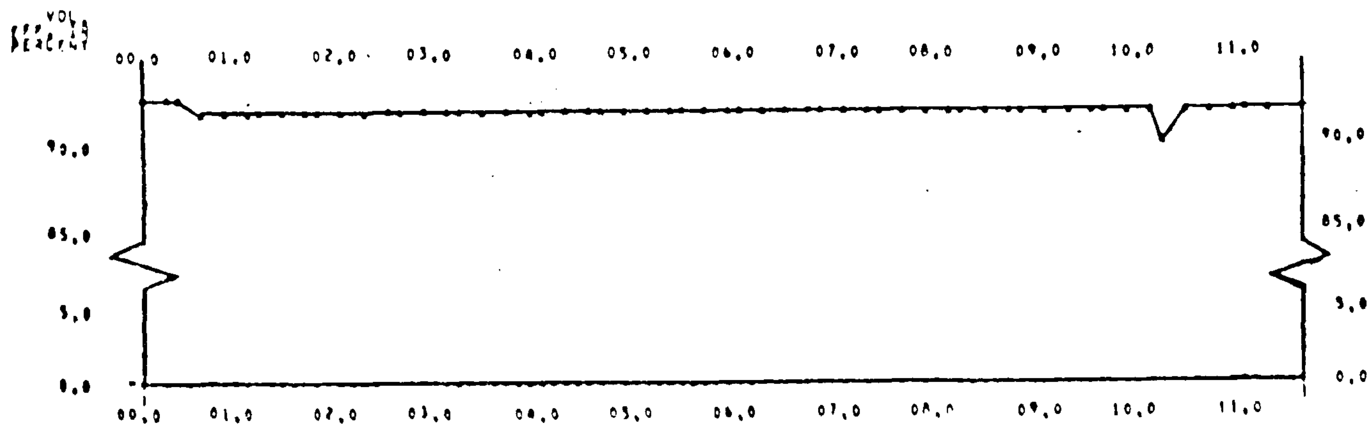



TIME IN MINUTES MULTIPLY BY 10[1]

93.136 IS MAX. MECH. EFF. IN PERCENT. 91.386 IS MIN.

112.000 IS MAX. TIME IN MINUTES. 0.000 IS MIN.

PART 1 ; PUMP CODE NO. 2333 - 120 DEG. F
SECTION 1.0A ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID



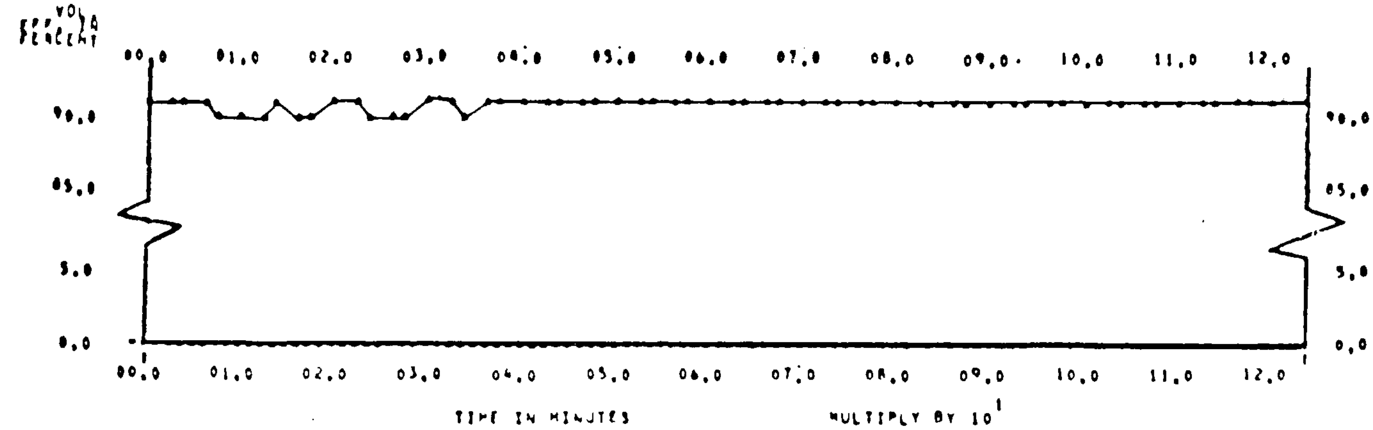

TIME IN MINUTES MULTIPLY BY 10[1]

92.650 IS MAX. VOL. EFF. IN PERCENT. 89.950 IS MIN.

112.000 IS MAX. TIME IN MINUTES. 0.000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

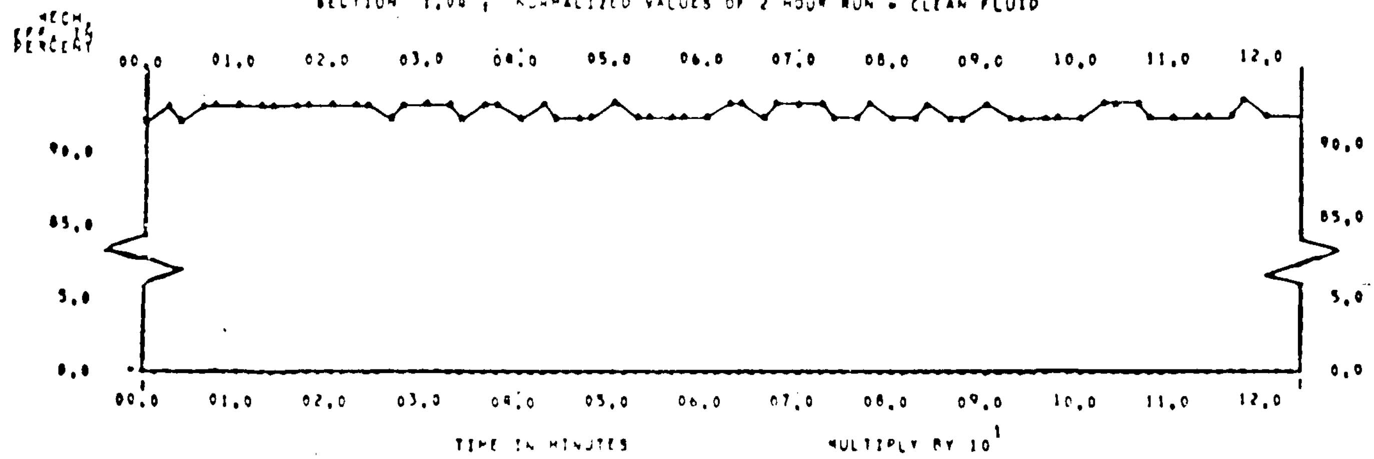
PART 1 ; PUMP CODE NO. 88378 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID




90.365 IS MAX. VOL. EFF. IN PERCENT. 89.804 IS MIN.

120.000 IS MAX. TIME IN MINUTES. 0.000 IS MIN.

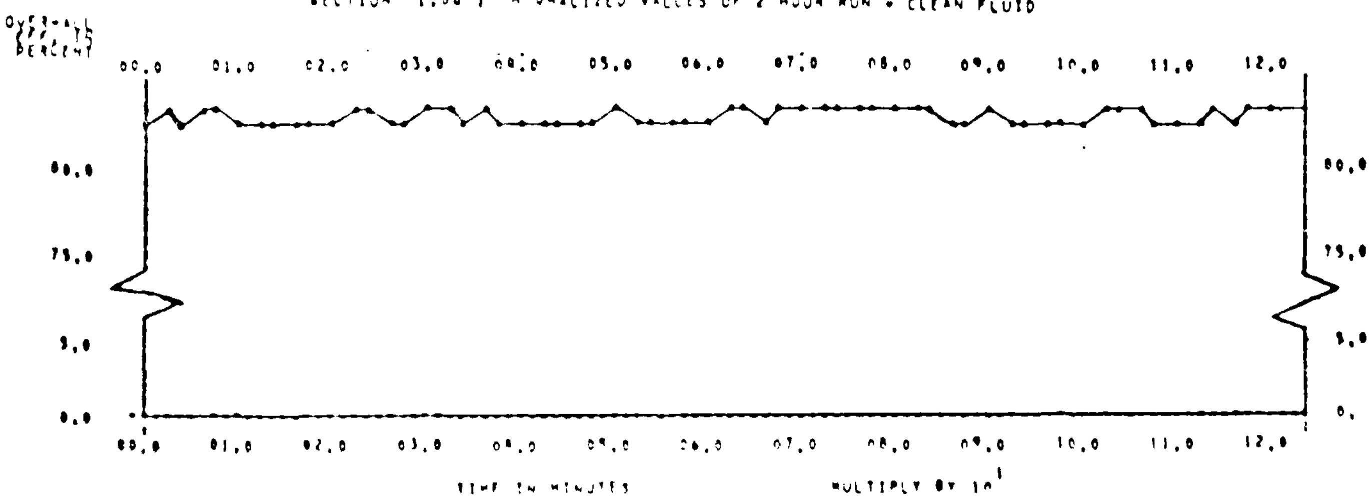
PART 1 ; PUMP CODE NO. 88378 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID




92.180 IS MAX. MECH. EFF. IN PERCENT. 91.137 IS MIN.

120.000 IS MAX. TIME IN MINUTES. 0.000 IS MIN.

PART 1 ; PUMP CODE NO. 88378 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

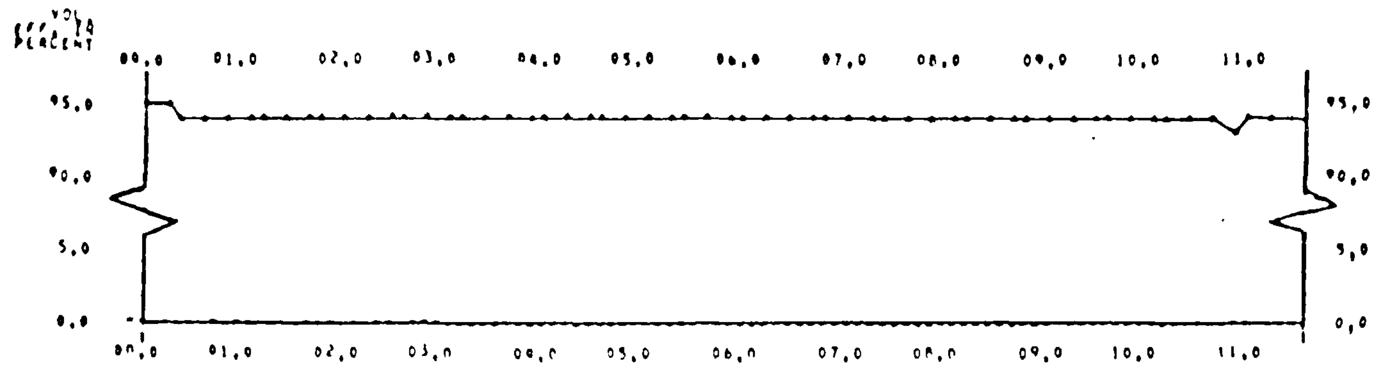



82.999 IS MAX. OVERALL EFF. IN PERCENT. 82.128 IS MIN.

120.000 IS MAX. TIME IN MINUTES. 0.000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART I I PUMP CODE NO. [illegible] - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

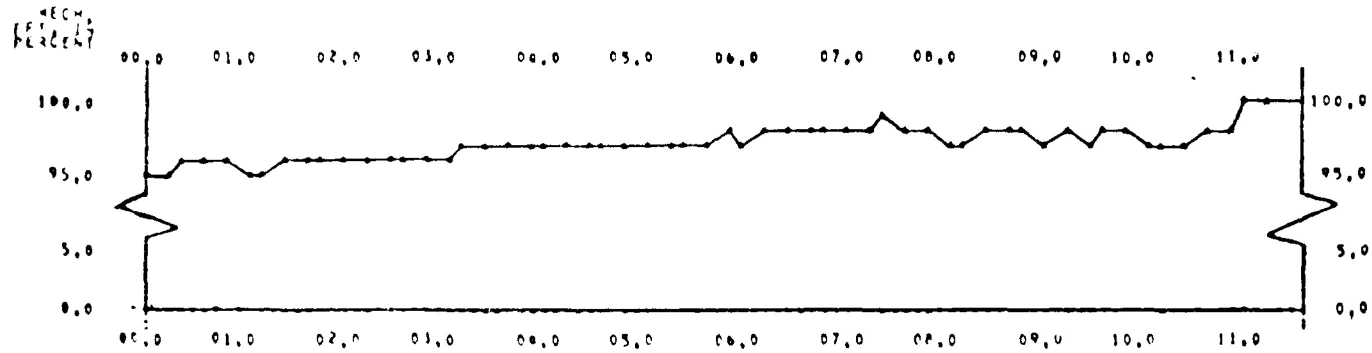



TIME IN MINUTES MULTIPLY BY $10^1$

94,200 IS MAX. VOL. EFF. IN PERCENT, 91,981 IS MIN.

112,000 IS MAX. TIME IN MINUTES, 0,000 IS MIN.

PART I I PUMP CODE NO. [illegible] - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

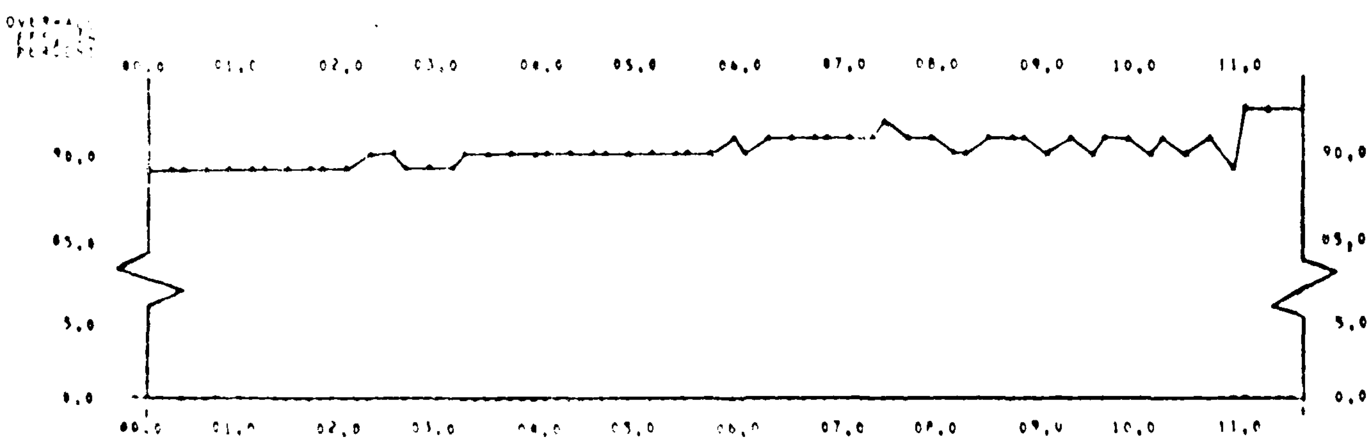



TIME IN MINUTES MULTIPLY BY $10^1$

99,531 IS MAX. MECH. EFF. IN PERCENT, 94,516 IS MIN.

112,000 IS MAX. TIME IN MINUTES, 0,000 IS MIN.

PART I I PUMP CODE NO. [illegible] - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID



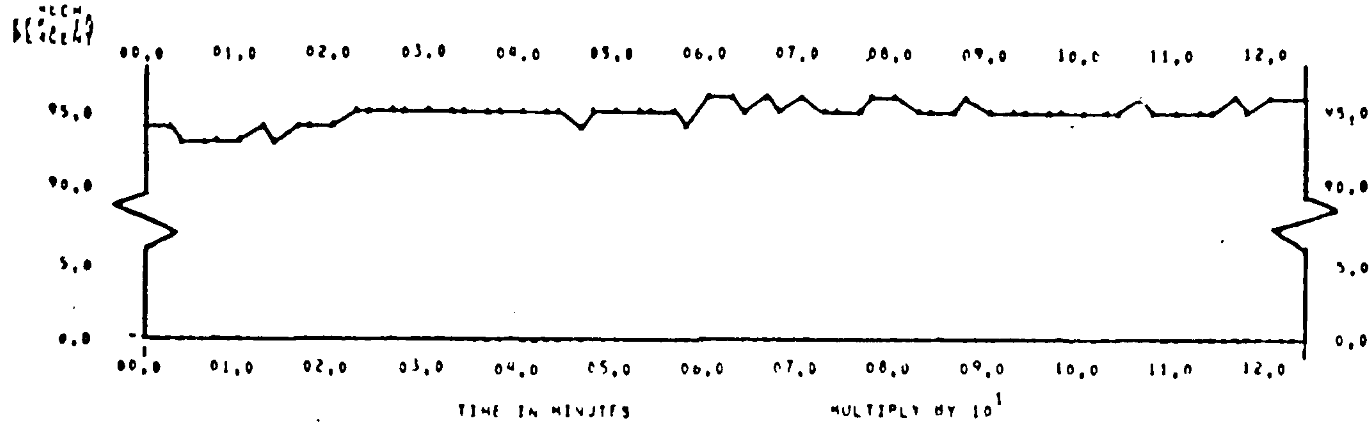

TIME IN MINUTES MULTIPLY BY $10^1$

92,885 IS MAX. OVERALL EFF. IN PERCENT, 88,885 IS MIN.

112,000 IS MAX. TIME IN MINUTES, 0,000 IS MIN.

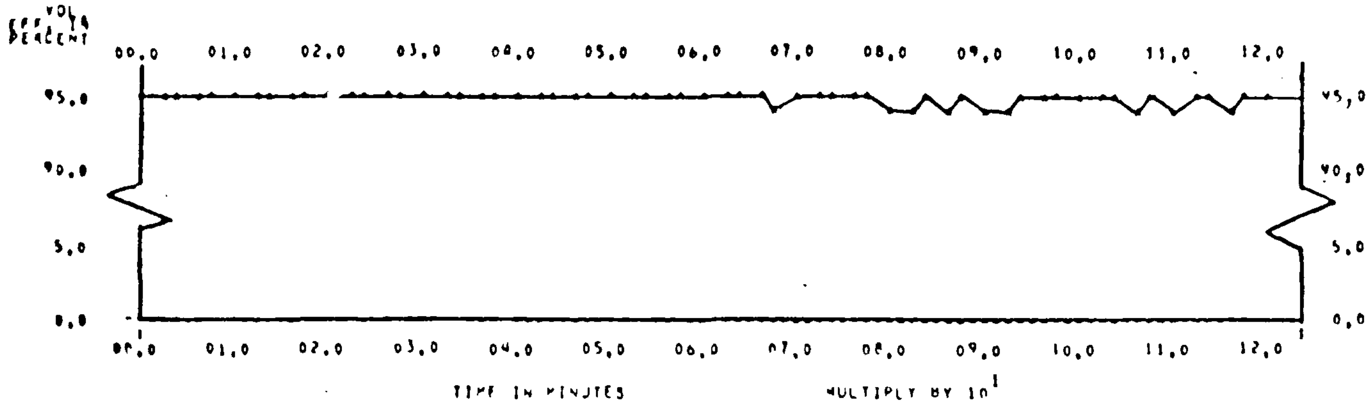
TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 I, PUMP CODE NO. 17083 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID



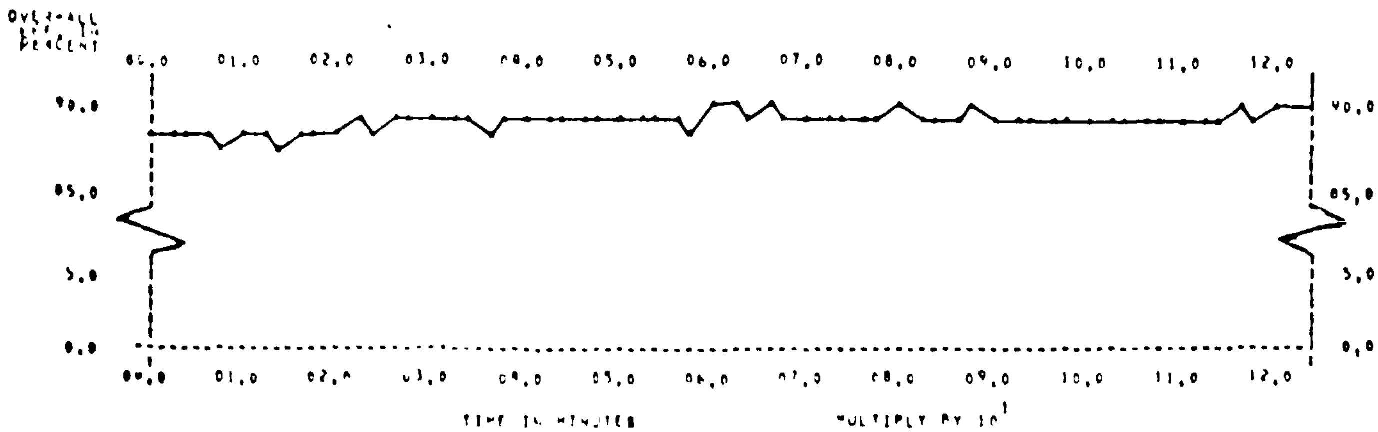

95,000 IS MAX, MECH, EFF, IN PERCENT, 92,229 IS MIN,
120,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

PART 1 I, PUMP CODE NO. 17083 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID




96,023 IS MAX, VOL, EFF, IN PERCENT, 94,252 IS MIN,
120,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

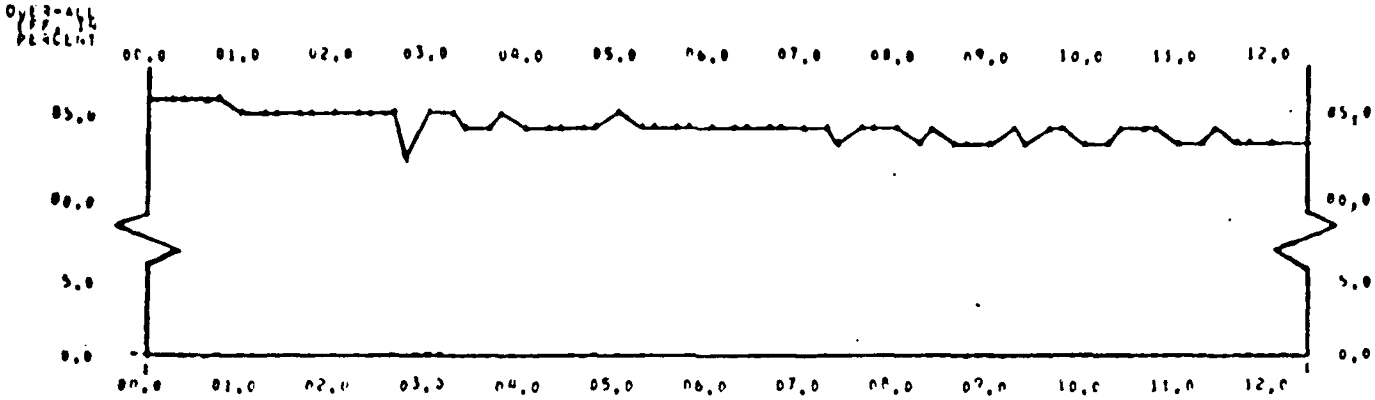
PART 1 I, PUMP CODE NO. 17083 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID




89,771 IS MAX, OVER-ALL EFF, IN PERCENT, 87,104 IS MIN,
120,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 ; PUMP CODE NO. 0815A - 120 DEG. F
SECTION 1.0[illegible] ; NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

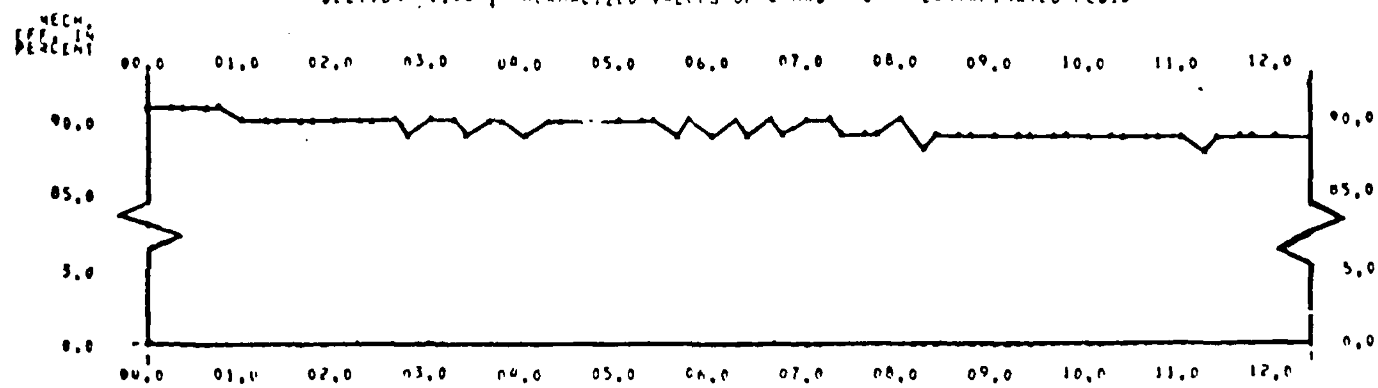



TIME IN MINUTES MULTIPLY BY 10[1]

85.535 IS MAX. OVER-ALL EFF. IN PERCENT. 82.072 IS MIN.

120.000 IS MAX. TIME IN MINUTES. 0.000 IS MIN.

PART 1 ; PUMP CODE NO. 0815A - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

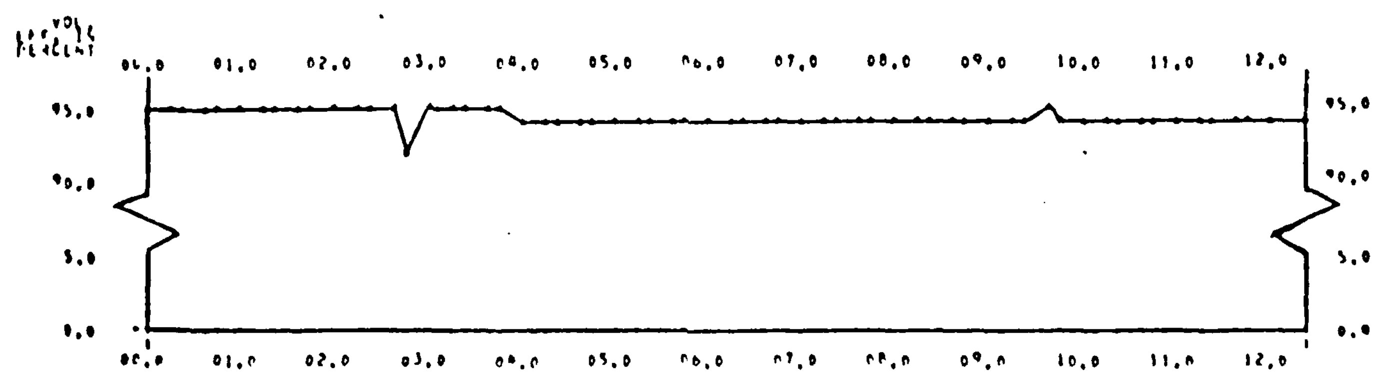



TIME IN MINUTES MULTIPLY BY 10[1]

90.455 IS MAX. MECH. EFF. IN PERCENT. 87.860 IS MIN.

120.000 IS MAX. TIME IN MINUTES. 0.000 IS MIN.

PART 1 ; PUMP CODE NO. 0815A - 120 DEG. F
SECTION 1.0[illegible] ; NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID



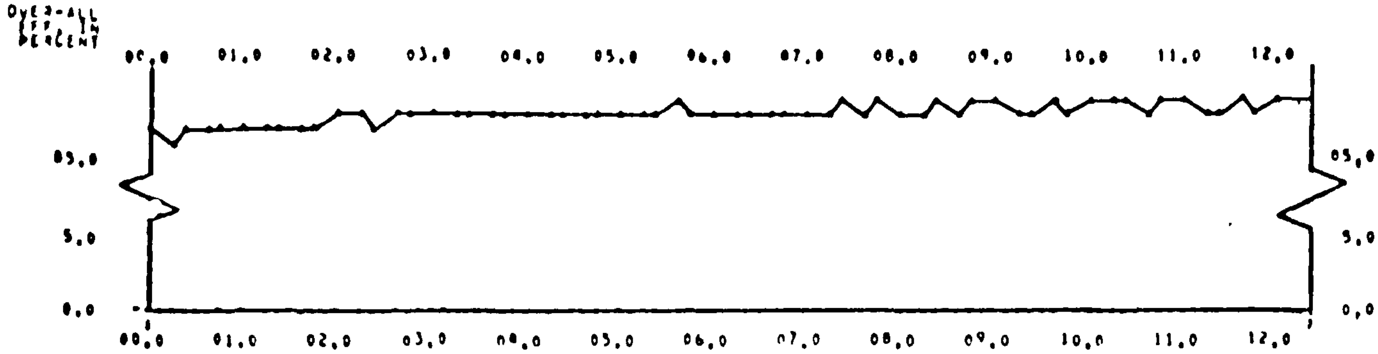

TIME IN MINUTES MULTIPLY BY 10[1]

94.754 IS MAX. VOL. EFF. IN PERCENT. 92.265 IS MIN.

120.000 IS MAX. TIME IN MINUTES. 0.000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 I, PUMP CODE NO. 68952 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

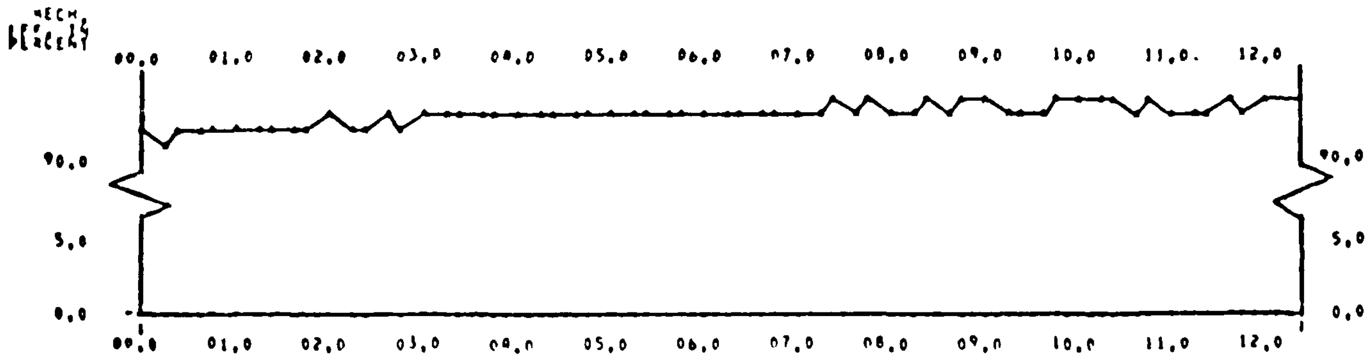



TIME IN MINUTES MULTIPLY BY $10^1$

88.590 IS MAX, OVER-ALL EFF. IN PERCENT, 86.179 IS MIN.

120.000 IS MAX, TIME IN MINUTES, 0.000 IS MIN.

PART 1 I, PUMP CODE NO. 68952 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

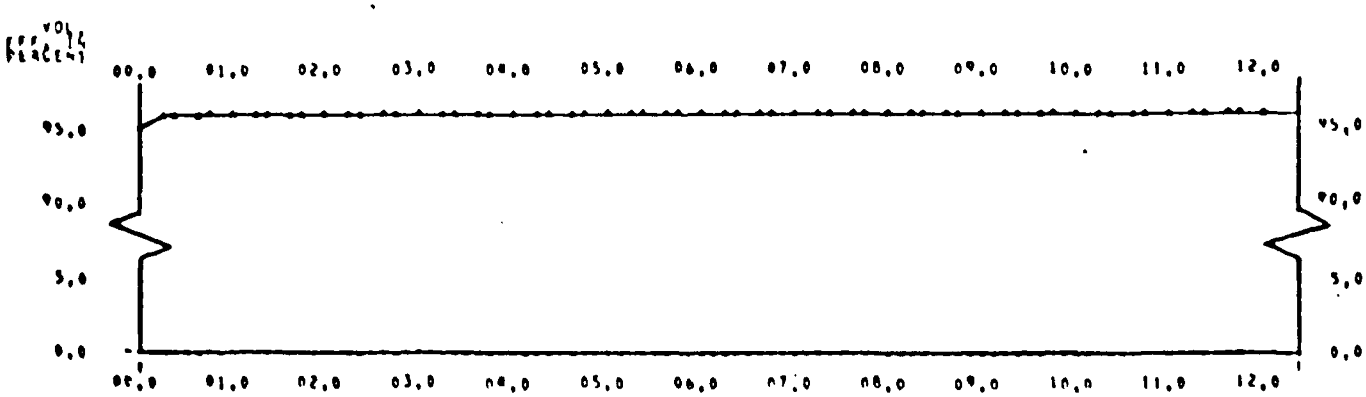



TIME IN MINUTES MULTIPLY BY $10^1$

93.133 IS MAX, MECH. EFF. IN PERCENT, 90.471 IS MIN.

120.000 IS MAX, TIME IN MINUTES, 0.000 IS MIN.

PART 1 I, PUMP CODE NO. 68952 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID



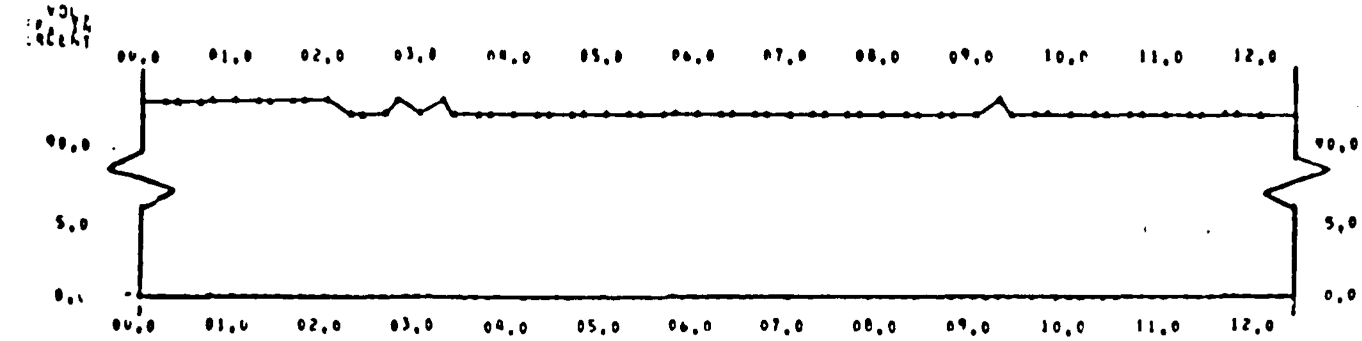

TIME IN MINUTES MULTIPLY BY $10^1$

95.296 IS MAX, VOL. EFF. IN PERCENT, 94.772 IS MIN.

120.000 IS MAX, TIME IN MINUTES, 0.000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART I, PUMP CODE NO. 18593 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

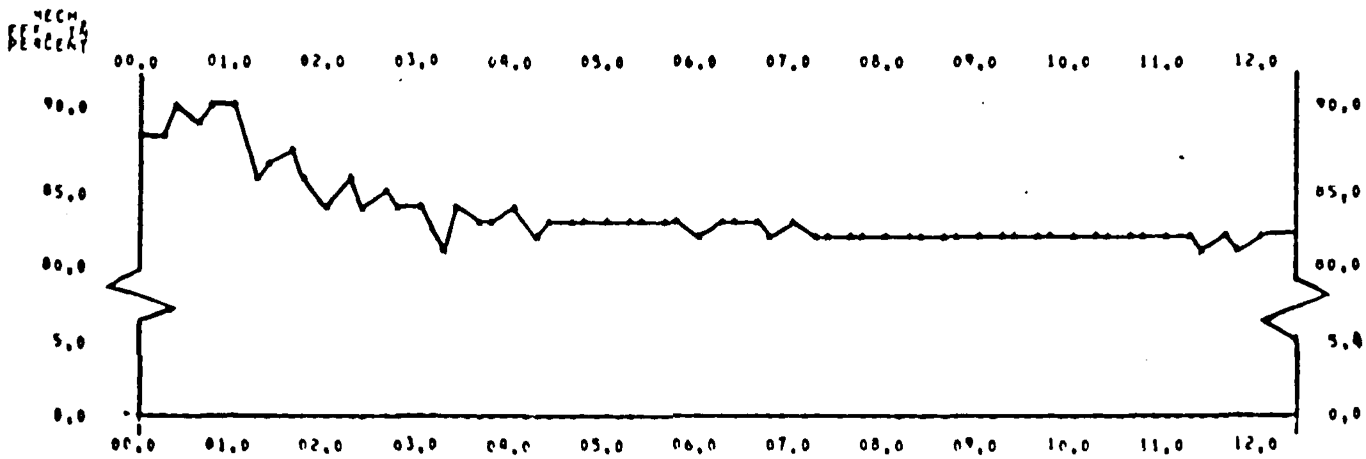



TIME IN MINUTES    MULTIPLY BY 10[1]

92,232 IS MAX. VOL. EFF. IN PERCENT.    91,178 IS MIN.

120,000 IS MAX. TIME IN MINUTES.    0,000 IS MIN.

PART I, PUMP CODE NO. 18593 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

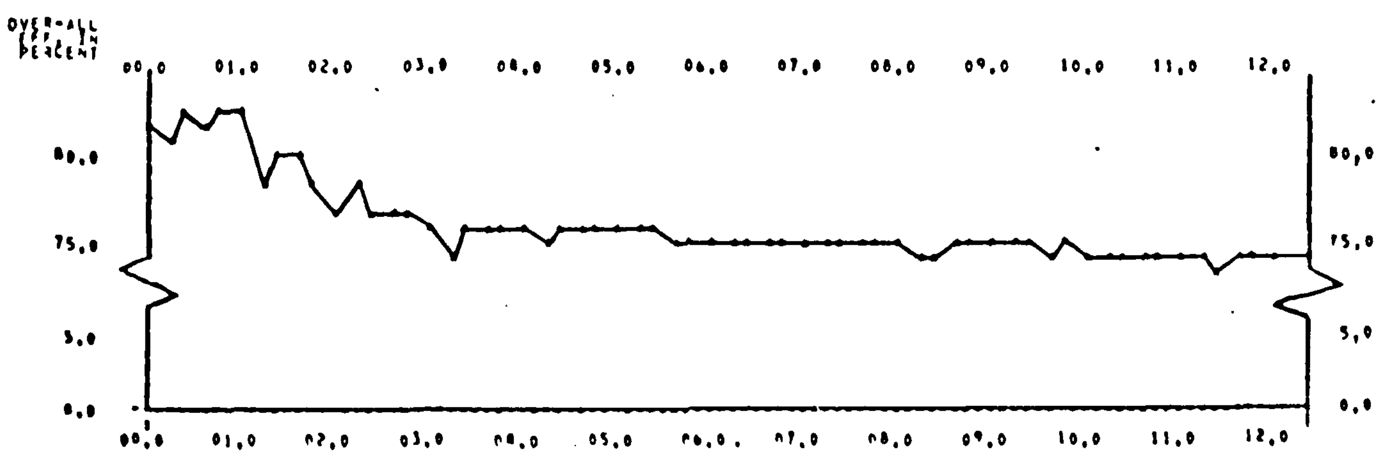



TIME IN MINUTES    MULTIPLY BY 10[1]

89,683 IS MAX. MECH. EFF. IN PERCENT.    80,063 IS MIN.

120,000 IS MAX. TIME IN MINUTES.    0,000 IS MIN.

PART I, PUMP CODE NO. 18593 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID



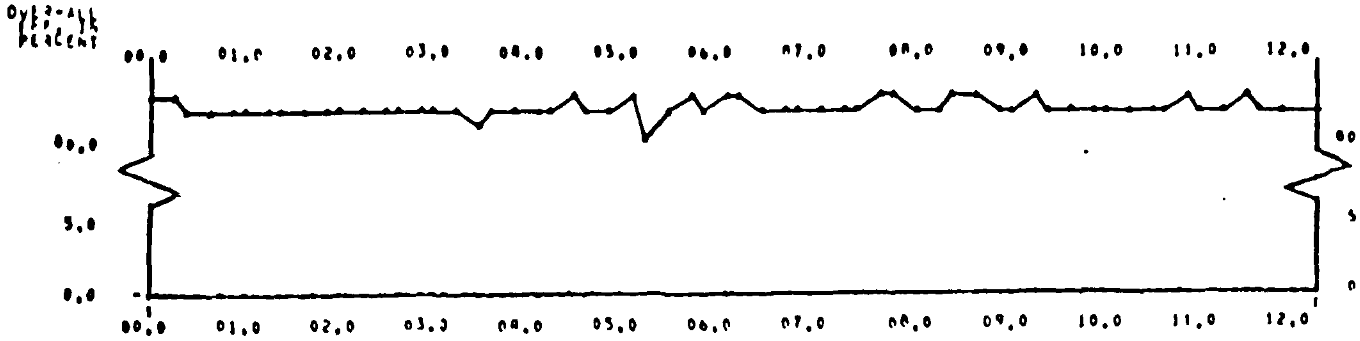

TIME IN MINUTES    MULTIPLY BY 10[1]

82,401 IS MAX. OVERALL EFF. IN PERCENT.    73,229 IS MIN.

120,000 IS MAX. TIME IN MINUTES.    0,000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 I, PUMP CODE NO. 58678 - 120 DEG. F
SECTION 1,04 I NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

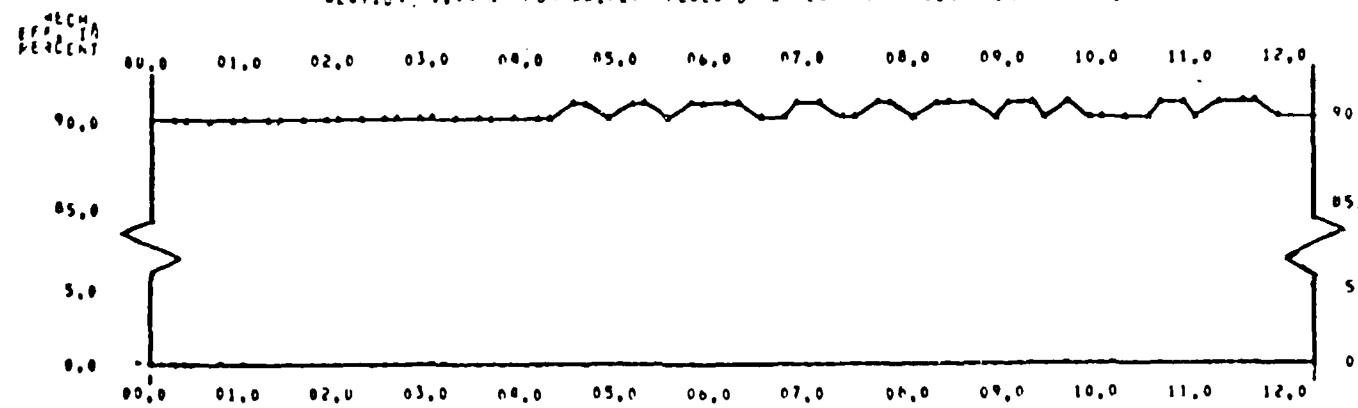



TIME IN MINUTES MULTIPLY BY $10^1$

82,255 IS MAX, OVER-ALL EFF, IN PERCENT, 79,678 IS MIN,

118,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

PART 1 I, PUMP CODE NO. 58678 - 120 DEG. F
SECTION 1,04 I NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

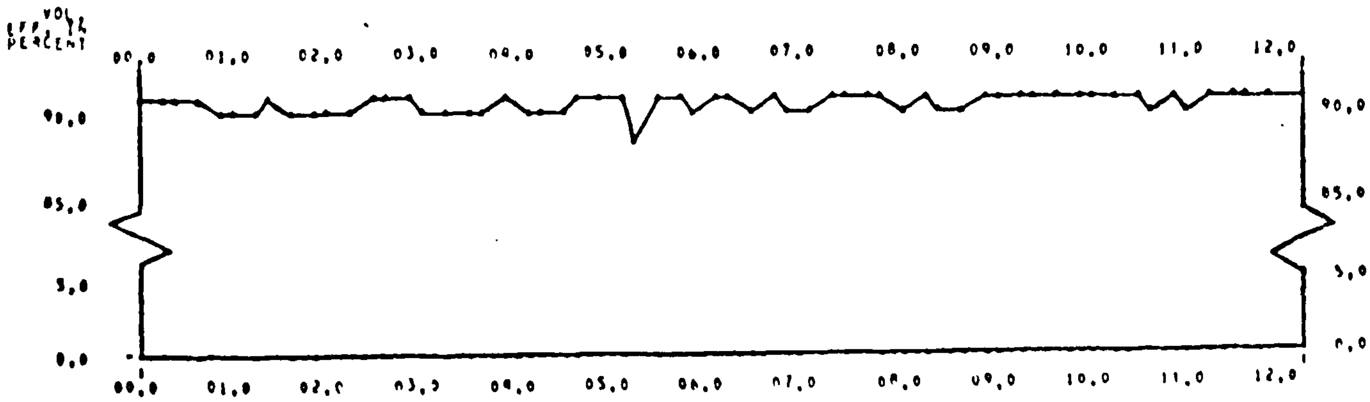



TIME IN MINUTES MULTIPLY BY $10^1$

90,923 IS MAX, MECH, EFF, IN PERCENT, 89,602 IS MIN,

118,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

PART 1 I, PUMP CODE NO. 58678 - 120 DEG. F
SECTION 1,04 I NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID



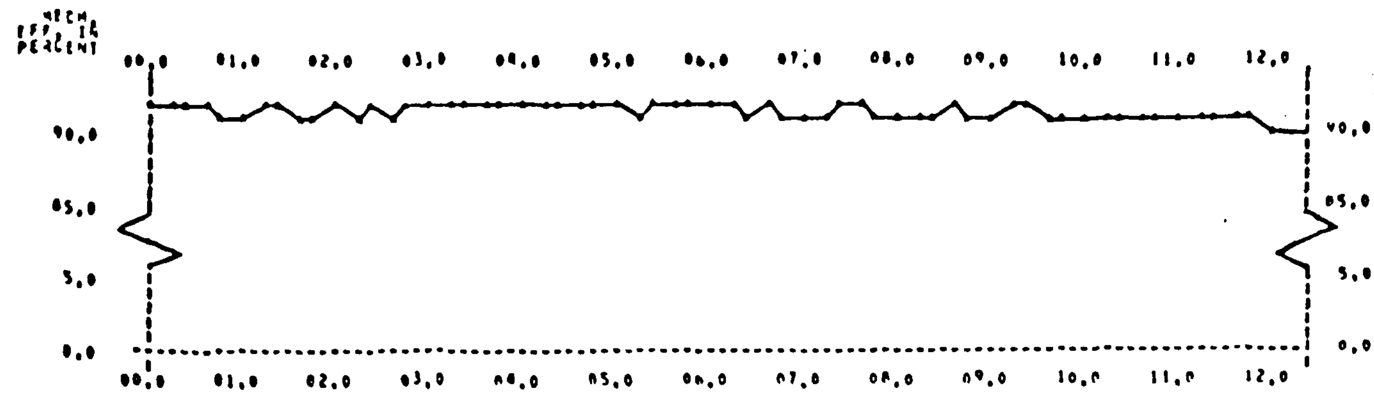

TIME IN MINUTES MULTIPLY BY $10^1$

90,876 IS MAX, VOL, EFF, IN PERCENT, 87,914 IS MIN,

118,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 1, PUMP CODE NO. 00087 - 120 DEG. F
SECTION 1.04 1 NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

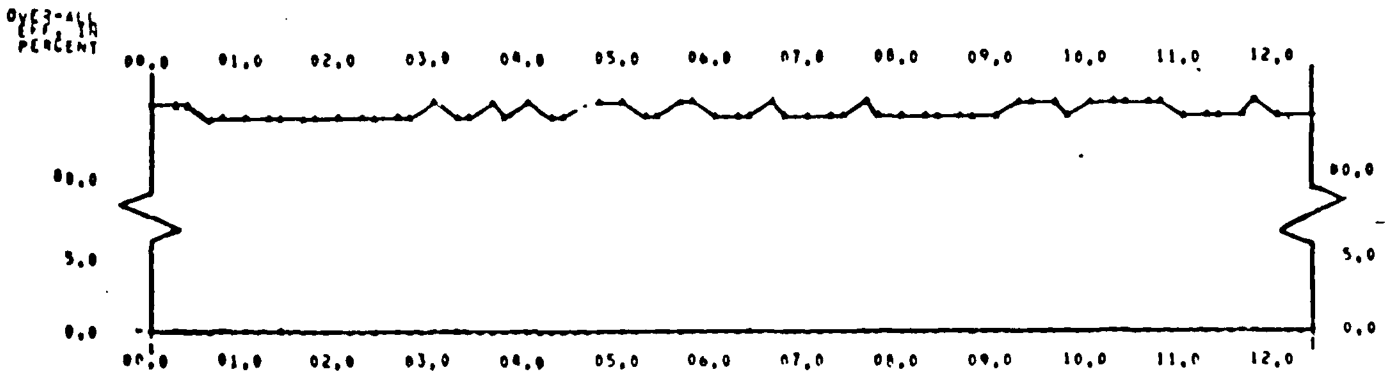



TIME IN MINUTES MULTIPLY BY $10^1$

91,811 IS MAX, MECH. EFF. IN PERCENT, 89,908 IS MIN.

120,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN.

PART 1 1, PUMP CODE NO. 00087 - 120 DEG. F
SECTION 1.04 1 NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID

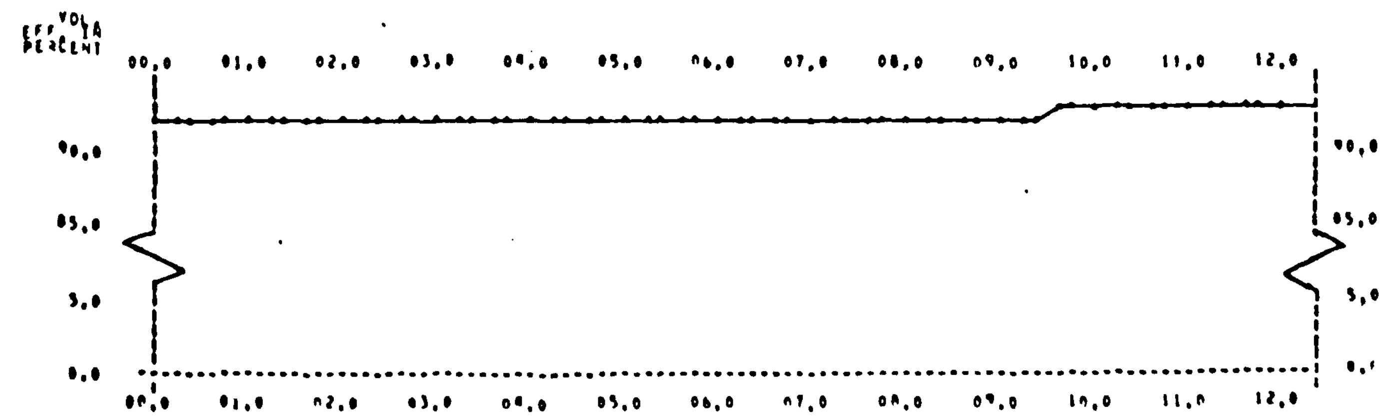



TIME IN MINUTES MULTIPLY BY $10^1$

83,681 IS MAX, OVER-ALL EFF. IN PERCENT, 82,470 IS MIN.

120,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN.

PART 1 1, PUMP CODE NO. 00087 - 120 DEG. F
SECTION 1.04 1 NORMALIZED VALUES OF 2 HOUR RUN - CONTAMINATED FLUID




TIME IN MINUTES MULTIPLY BY $10^1$

92,189 IS MAX, VOL. EFF. IN PERCENT, 90,977 IS MIN.

120,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN.

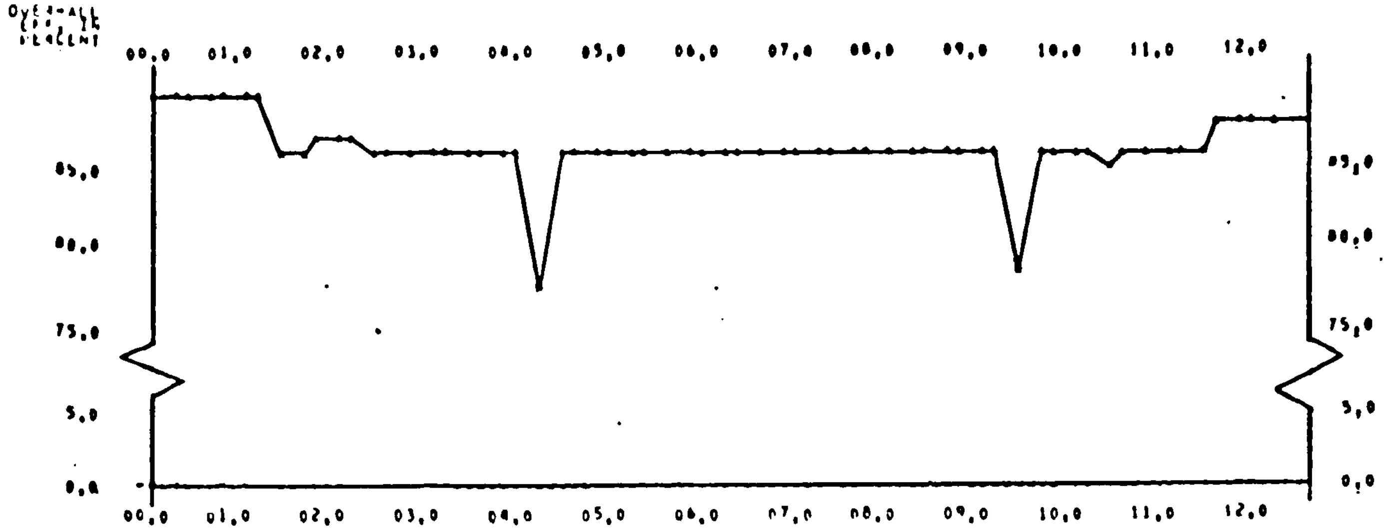
### 1.7.5 GRAPHICAL DATA - TWO HOUR RUN

#### 1.7.5.2 Contaminated Fluid

| Manufacturer | Pump Code No. |
|---|---|
| 1 | 44947 |
| | 58678 |
| 2 | 18593 |
| | 64952 |
| 3 | 17983 |
| | 08158 |

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 I, PUMP CODE NO. 18103 - 120 DEG. F.
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

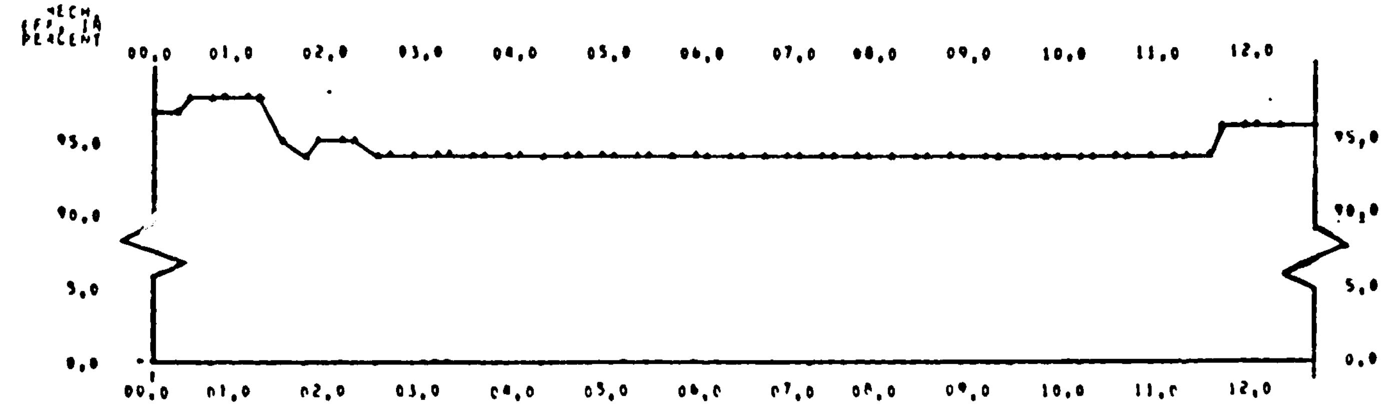



TIME IN MINUTES MULTIPLY BY $10^1$

88,728 IS MAX, OVER-ALL EFF, IN PERCENT, 76,555 IS MIN,

122,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

PART 1 I, PUMP CODE NO. 18103 - 120 DEG. F.
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

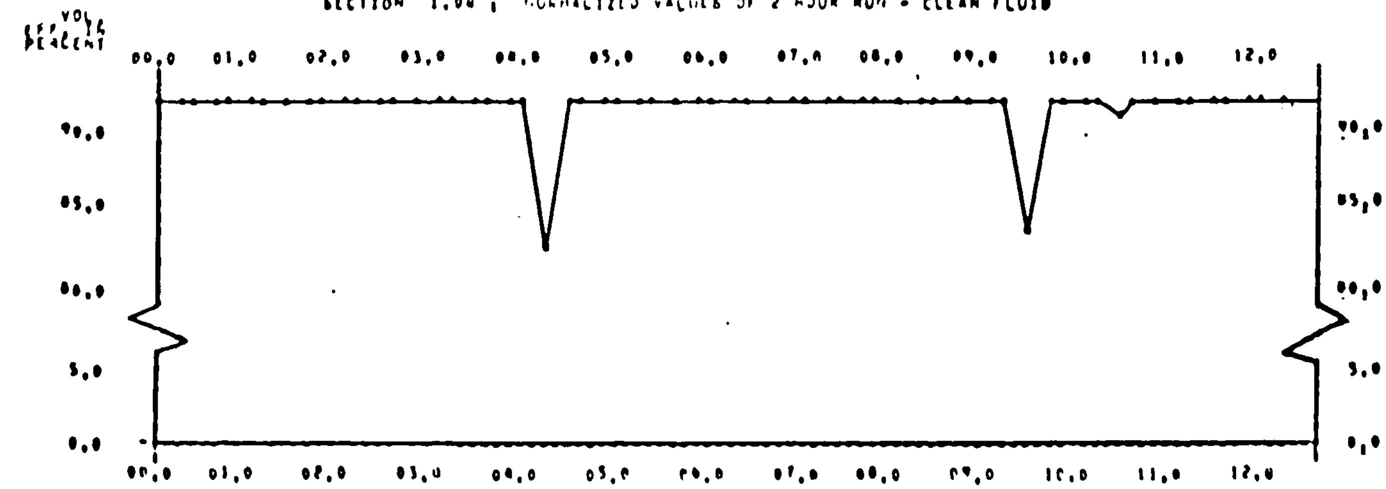



TIME IN MINUTES MULTIPLY BY $10^1$

97,548 IS MAX, MECH, EFF, IN PERCENT, 93,194 IS MIN,

122,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

PART 1 I, PUMP CODE NO. 18103 - 120 DEG. F.
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID



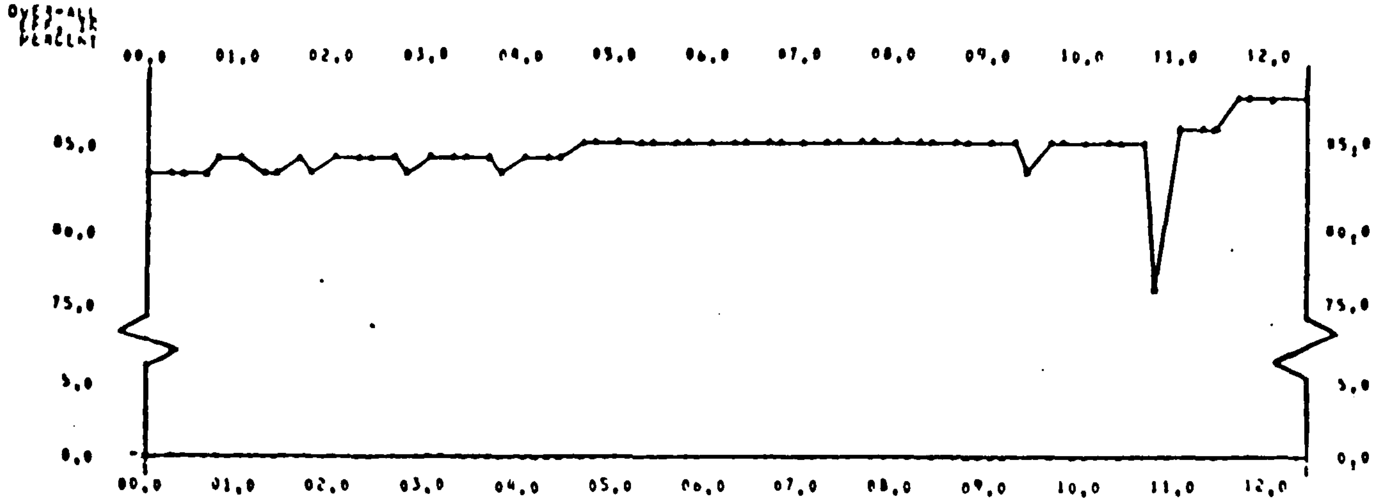

TIME IN MINUTES MULTIPLY BY $10^1$

91,205 IS MAX, VOL, EFF, IN PERCENT, 81,608 IS MIN,

122,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 I, PUMP CODE NO. 17453 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

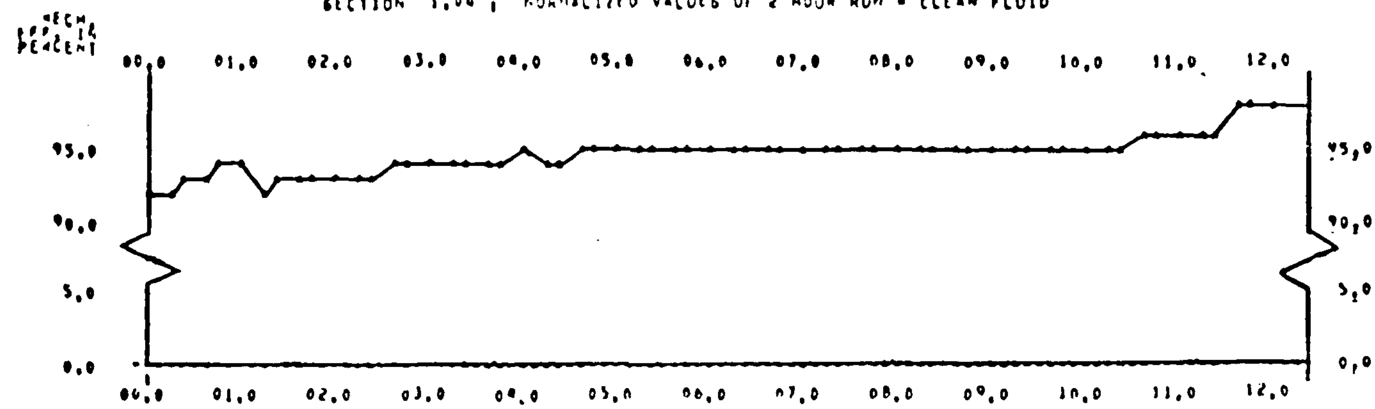



TIME IN MINUTES MULTIPLY BY 10[1]

87,266 IS MAX, OVER-ALL EFF. IN PERCENT, 75,881 IS MIN.

120,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN.

PART 1 I, PUMP CODE NO. 17453 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

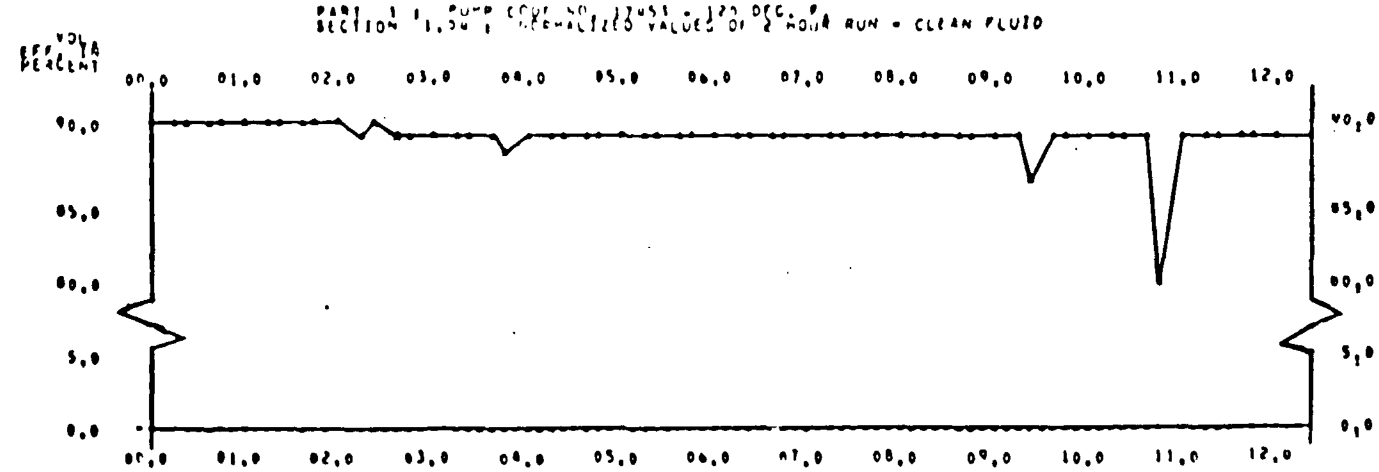



TIME IN MINUTES MULTIPLY BY 10[1]

97,852 IS MAX, MECH. EFF. IN PERCENT, 91,794 IS MIN.

120,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN.

PART 1 I, PUMP CODE NO. 17453 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID



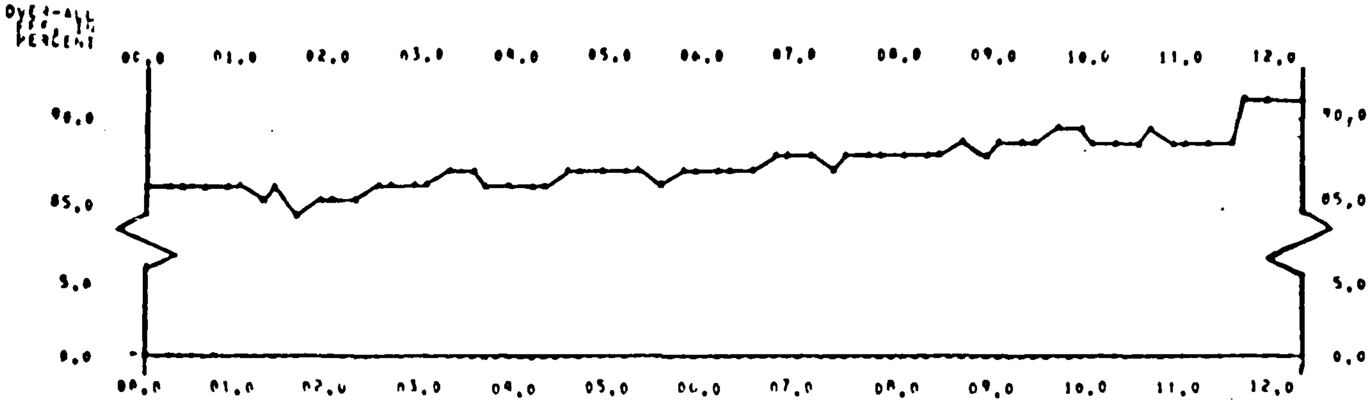

TIME IN MINUTES MULTIPLY BY 10[1]

89,836 IS MAX, VOL. EFF. IN PERCENT, 79,898 IS MIN.

120,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 1, PUMP CODE NO. 10281 - 120 DEG. F
SECTION 1.04 1 NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

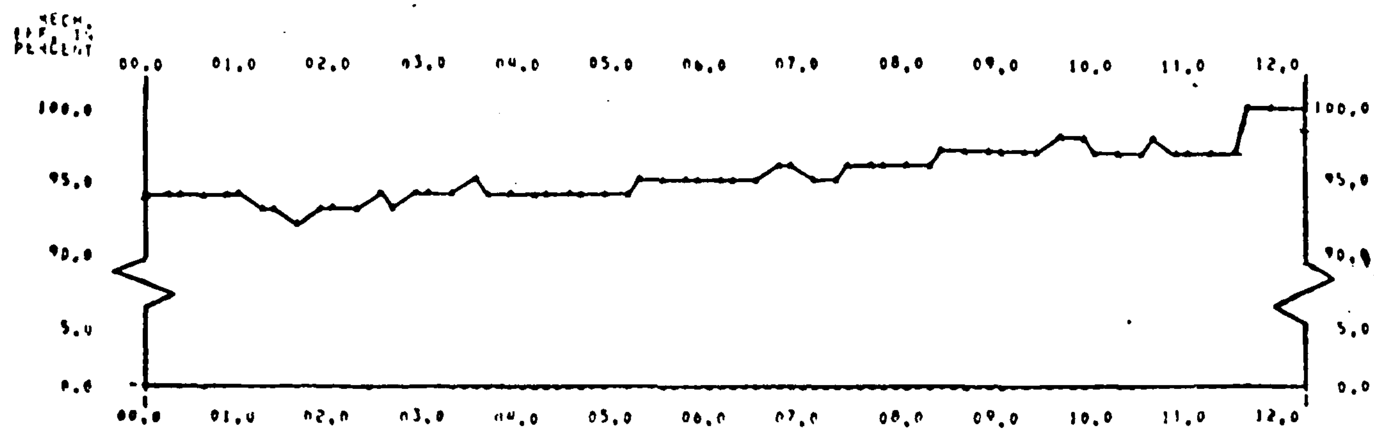



TIME IN MINUTES MULTIPLY BY $10^1$

90,707 IS MAX, OVER-ALL EFF. IN PERCENT. 83,486 IS MIN.

118,000 IS MAX, TIME IN MINUTES. 0,000 IS MIN.

PART 1 1, PUMP CODE NO. 10281 - 120 DEG. F
SECTION 1.04 1 NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

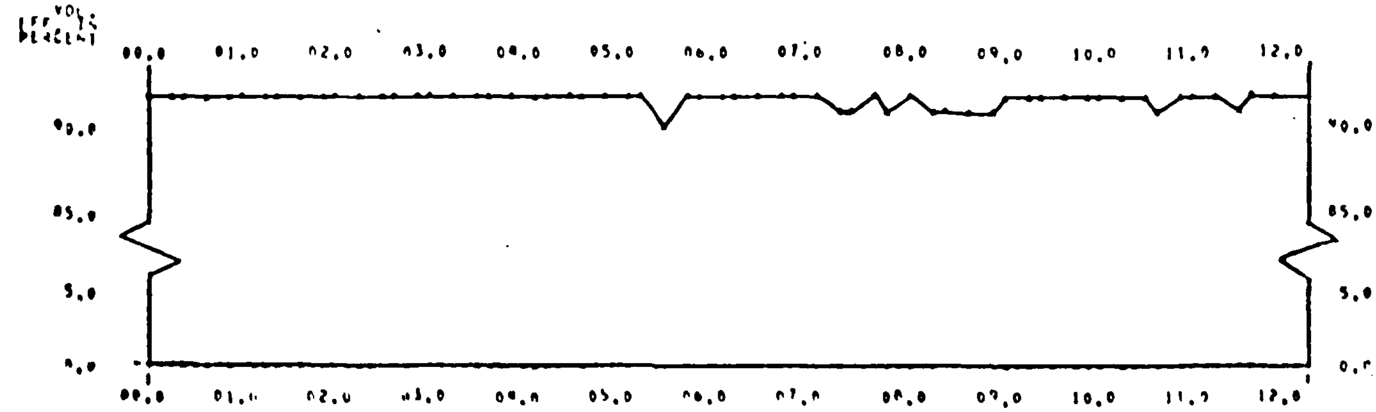



TIME IN MINUTES MULTIPLY BY $10^1$

99,543 IS MAX, MECH. EFF. IN PERCENT. 91,334 IS MIN.

118,000 IS MAX, TIME IN MINUTES. 0,000 IS MIN.

PART 1 1, PUMP CODE NO. 10281 - 120 DEG. F
SECTION 1.04 1 NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID



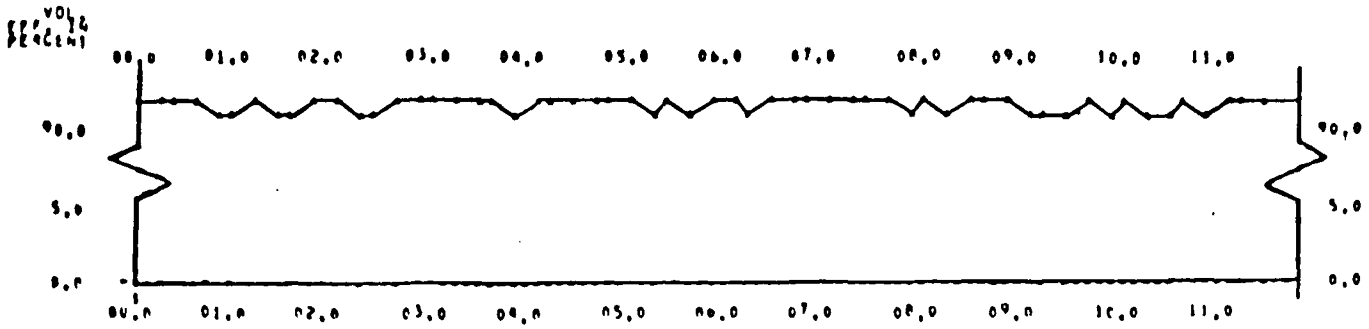

TIME IN MINUTES MULTIPLY BY $10^1$

91,590 IS MAX, VOL. EFF. IN PERCENT. 90,079 IS MIN.

118,000 IS MAX, TIME IN MINUTES. 0,000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 : PUMP CODE NO. 53661 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

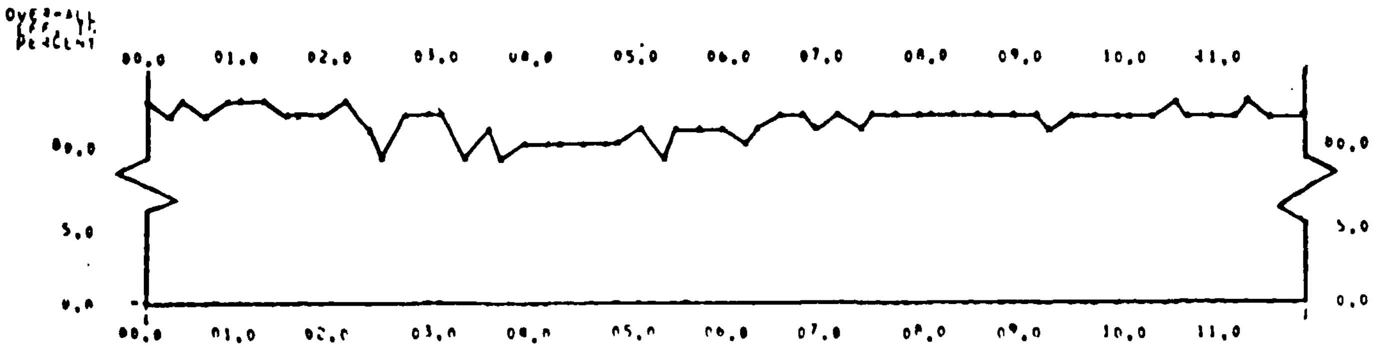



TIME IN MINUTES MULTIPLY BY $10^1$

91,823 IS MAX, VOL. EFF. IN PERCENT, 91,080 IS MIN.

11[illegible],000 IS MAX, TIME IN MINUTES, 0,000 IS MIN.

PART 1 : PUMP CODE NO. 53661 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

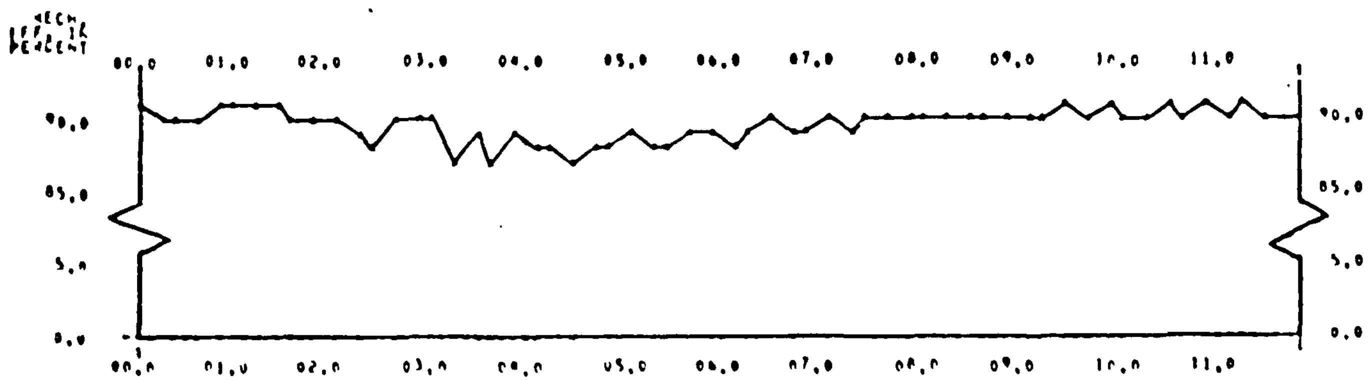



TIME IN MINUTES MULTIPLY BY $10^1$

8[illegible] IS MAX, OVER-ALL EFF. IN PERCENT, 79,247 IS MIN.

11[illegible] IS MAX, TIME IN MINUTES, 0,000 IS MIN.

PART 1 : PUMP CODE NO. 53661 - 120 DEG. F
SECTION 1.04 : NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID



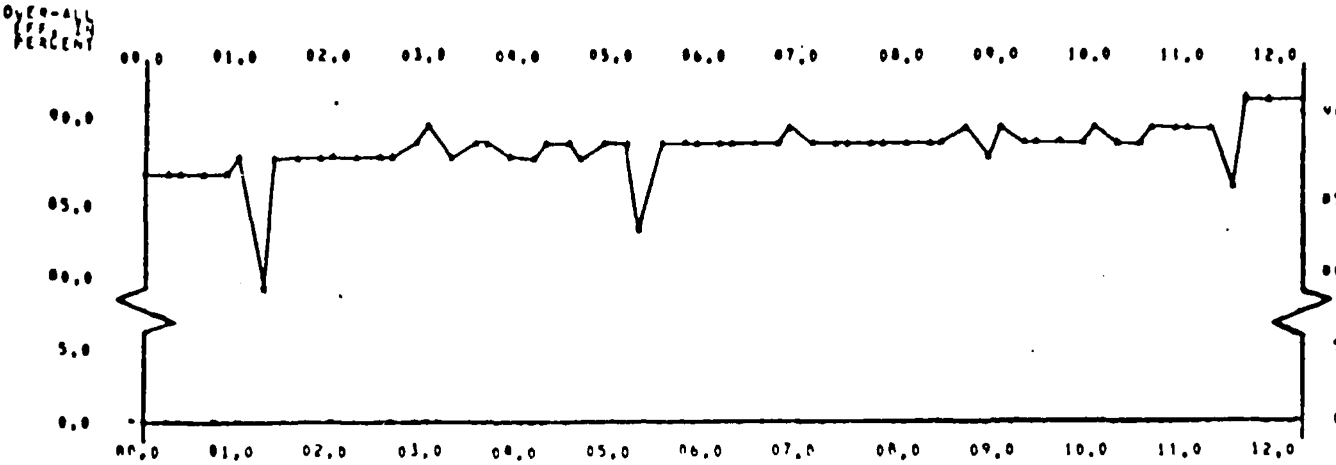

TIME IN MINUTES MULTIPLY BY $10^1$

9[illegible],110 IS MAX, MECH. EFF. IN PERCENT, 86,679 IS MIN.

11[illegible],000 IS MAX, TIME IN MINUTES, 0,000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 ; PUMP CODE NO. 05585 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

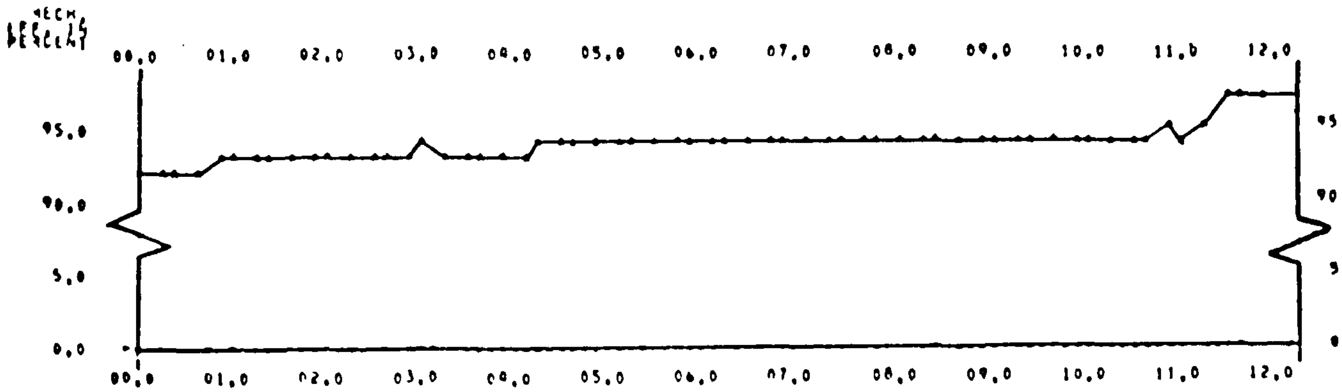



TIME IN MINUTES MULTIPLY BY 10[1]

90,403 IS MAX, OVER-ALL EFF, IN PERCENT, 78,363 IS MIN,

118,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

PART 1 ; PUMP CODE NO. 05585 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

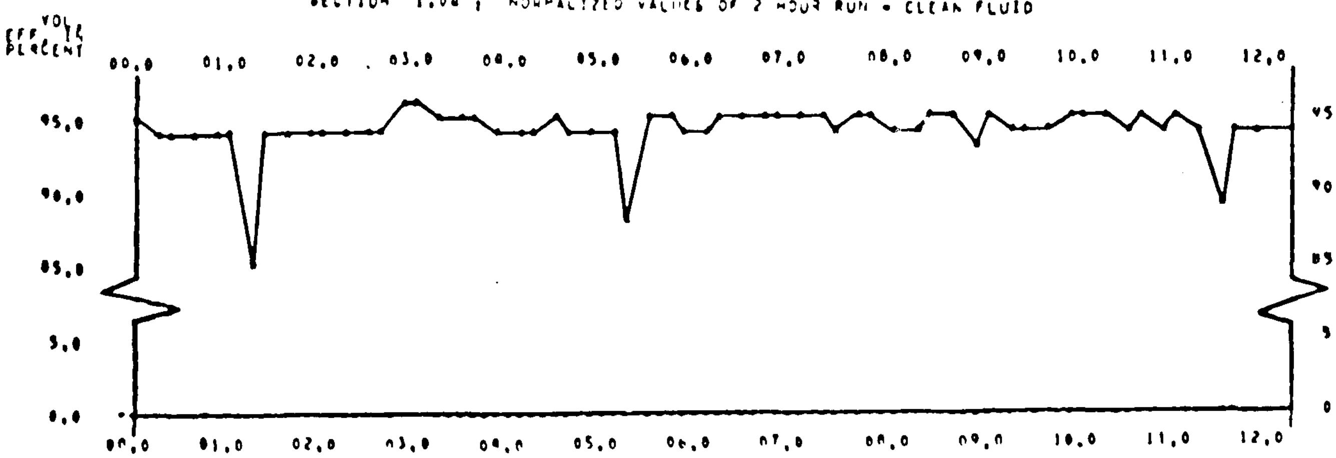



TIME IN MINUTES MULTIPLY BY 10[1]

96,452 IS MAX, MECH. EFF, IN PERCENT, 91,060 IS MIN,

118,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

PART 1 ; PUMP CODE NO. 05585 - 120 DEG. F
SECTION 1.04 ; NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

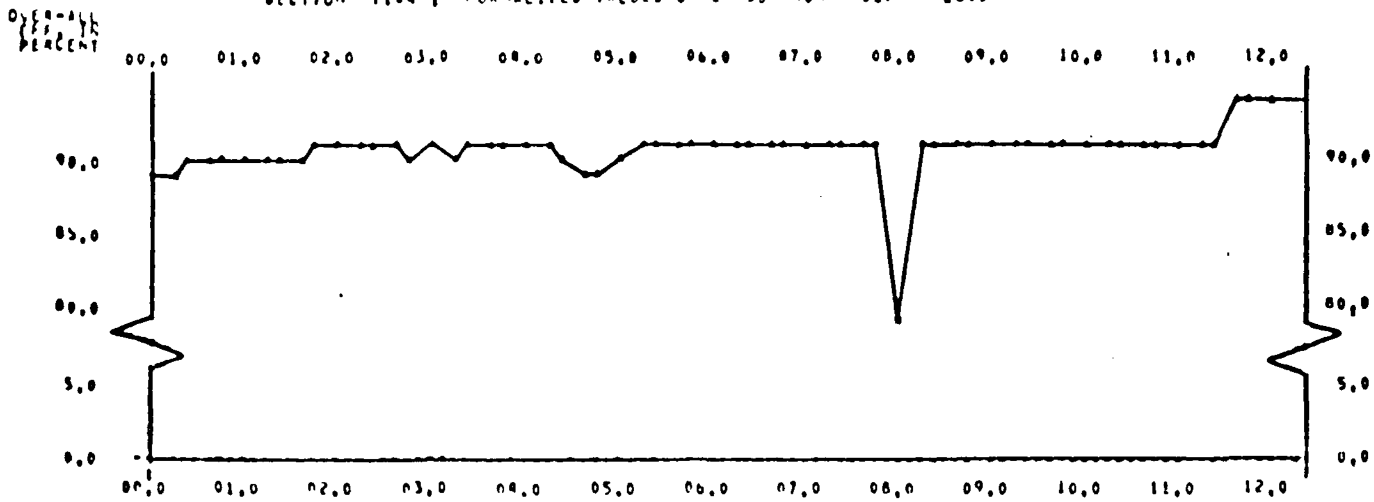



TIME IN MINUTES MULTIPLY BY 10[1]

95,352 IS MAX, VOL. EFF, IN PERCENT, 84,562 IS MIN,

118,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

PART 1 I, PUMP CODE NO. 18439 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

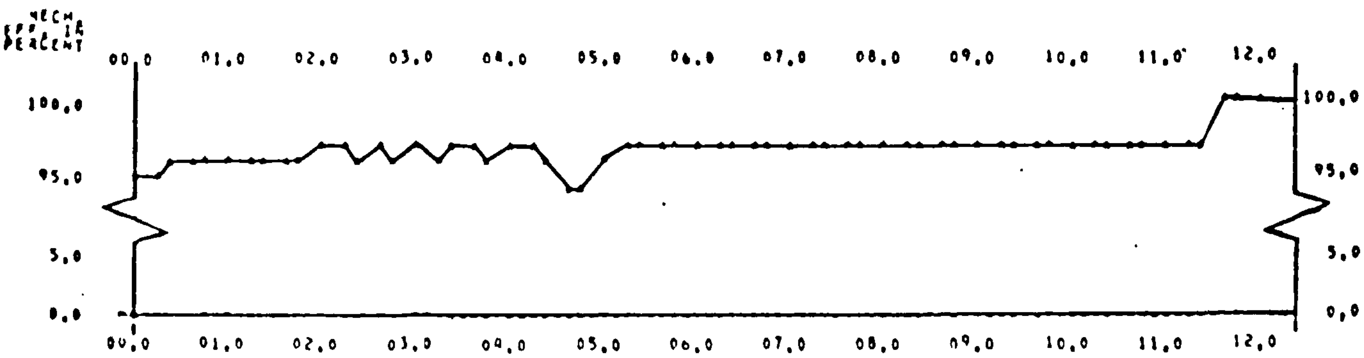



TIME IN MINUTES MULTIPLY BY $10^1$

93.266 IS MAX, OVERALL EFF. IN PERCENT, 79.005 IS MIN.

120.000 IS MAX, TIME IN MINUTES, 0.000 IS MIN.

PART 1 I, PUMP CODE NO. 18439 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

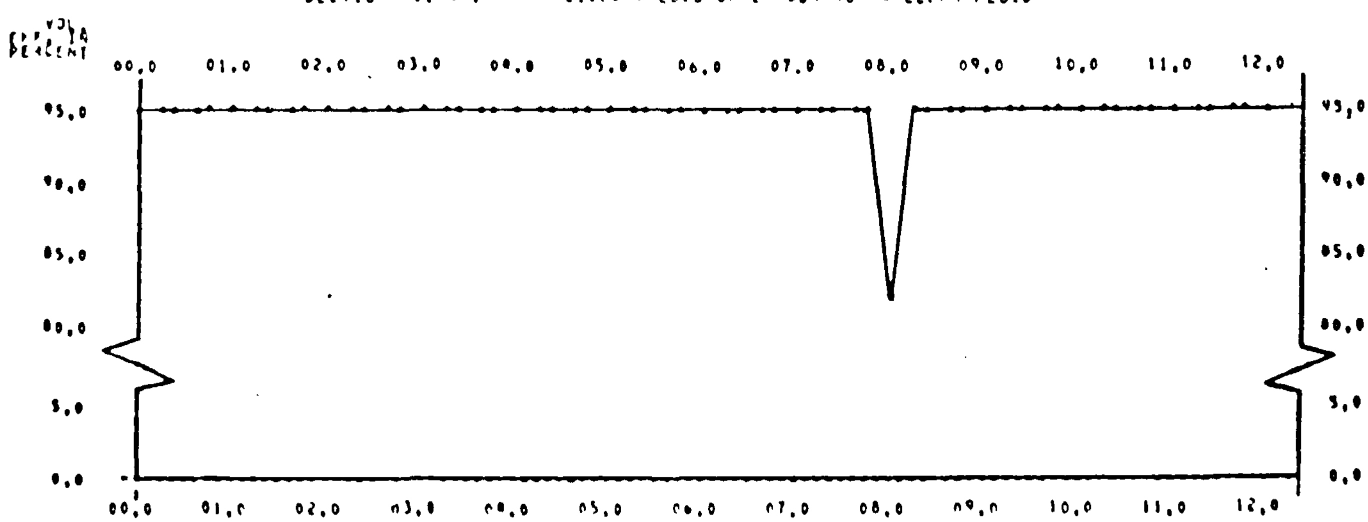



TIME IN MINUTES MULTIPLY BY $10^1$

99.257 IS MAX, MECH. EFF. IN PERCENT, 93.677 IS MIN.

120.000 IS MAX, TIME IN MINUTES, 0.000 IS MIN.

PART 1 I, PUMP CODE NO. 18439 - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID



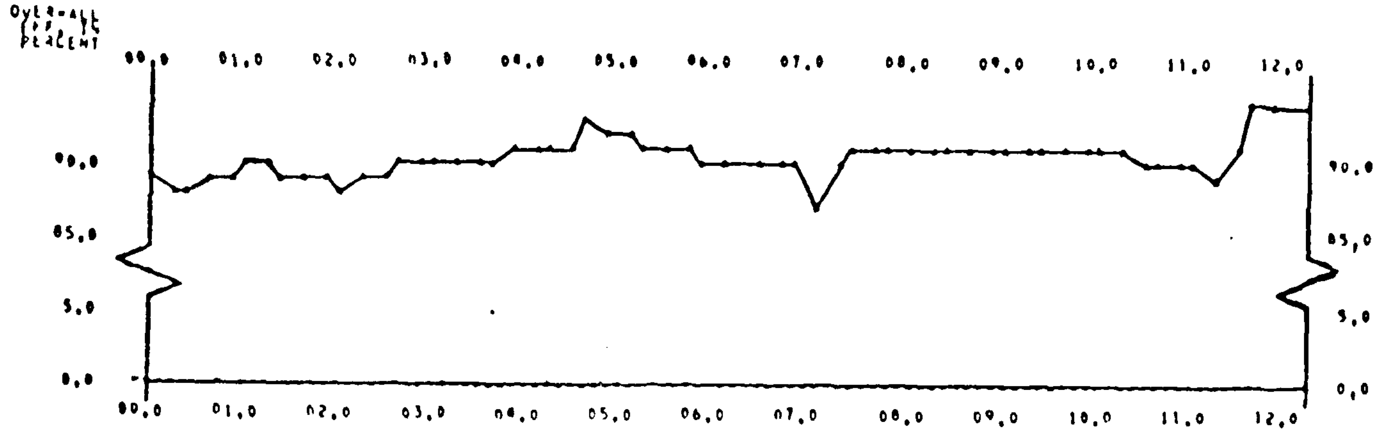

TIME IN MINUTES MULTIPLY BY $10^1$

94.263 IS MAX, VOL. EFF. IN PERCENT, 82.039 IS MIN.

120.000 IS MAX, TIME IN MINUTES, 0.000 IS MIN.

TESTS CONDUCTED BY FLUID POWER INSTITUTE, MILWAUKEE SCHOOL OF ENGINEERING

PART 1 I, PUMP CODE NO. 11050A - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

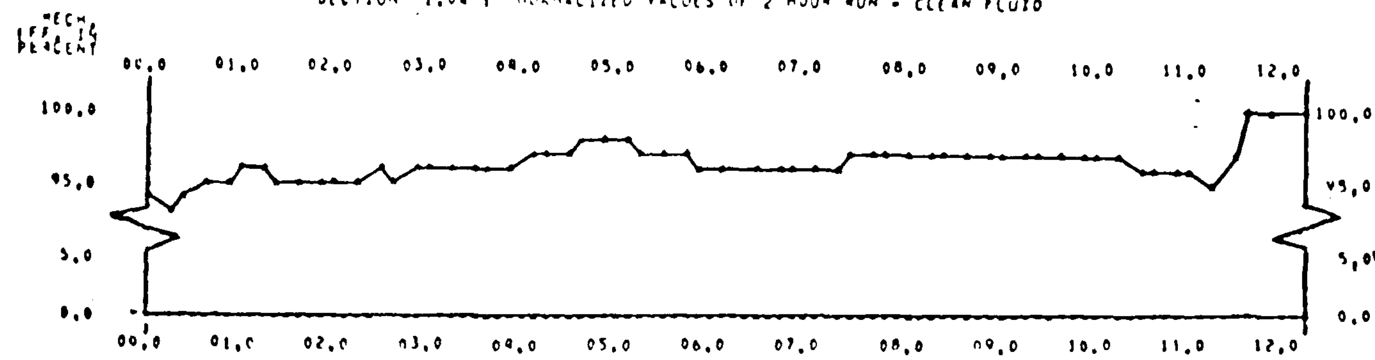



TIME IN MINUTES MULTIPLY BY 10[1]

92,975 IS MAX, OVERALL EFF, IN PERCENT, 68,552 IS MIN,

118,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

PART 1 I, PUMP CODE NO. 11050A - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID

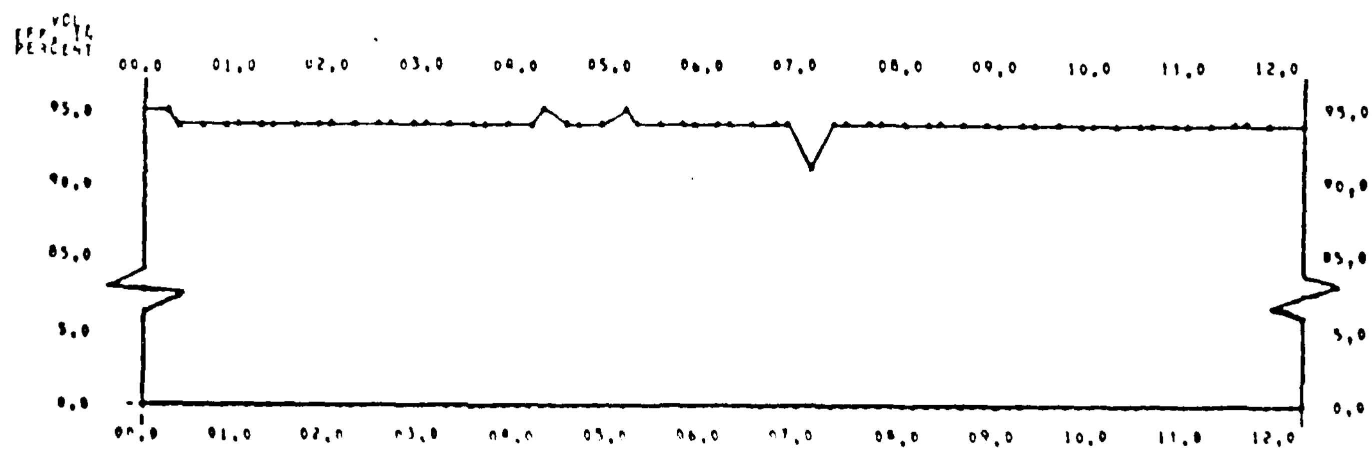



TIME IN MINUTES MULTIPLY BY 10[1]

99,397 IS MAX, MECH, EFF, IN PERCENT, 73,282 IS MIN,

118,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,

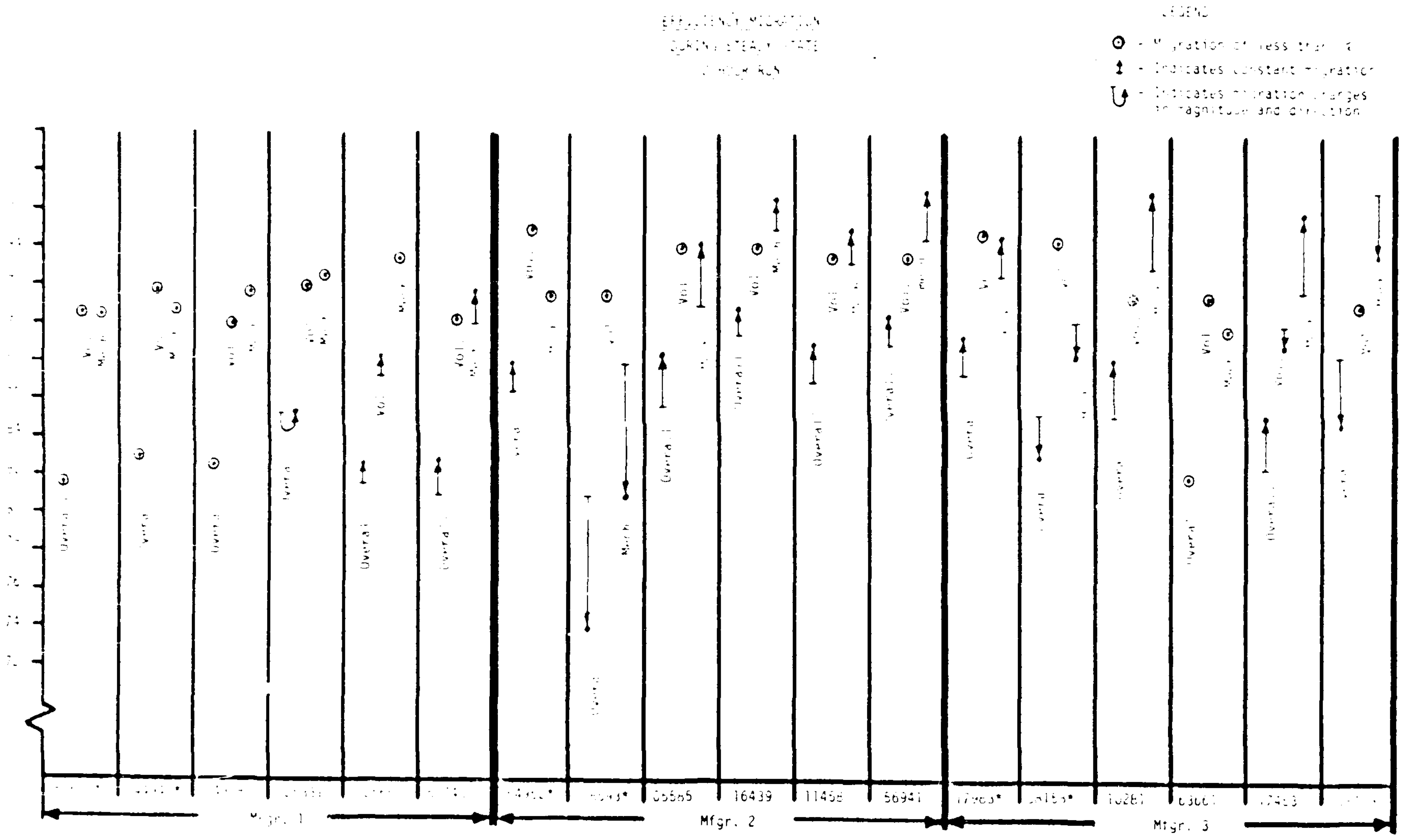
PART 1 I, PUMP CODE NO. 11050A - 120 DEG. F
SECTION 1.04 I NORMALIZED VALUES OF 2 HOUR RUN - CLEAN FLUID




TIME IN MINUTES MULTIPLY BY 10[1]

96,2[illegible] IS MAX, VOL, EFF, IN PERCENT, 90,730 IS MIN,

118,000 IS MAX, TIME IN MINUTES, 0,000 IS MIN,




*Pumps tested with contaminated fluid

PUMP CODE NUMBERS

This chart is a summary of the data recorded during the two hour steady state break-in test. The two hour break-in test was performed immediately after a 1/2 hour cyclic break-in test. A representative graph of that cyclic break-in test is located in section 1.7.3.3

Figure No. 1.7.2

J.M.
6/25/79

## 1.8.1 TABULATED CONTAMINATION DATA

### PARTICLE COUNT RESULTS OF THE CLEAN FLUID BREAK-IN TEST

Initially, the system fluid was cleaned up to a level of 100 particles per millilitre greater than ten micrometres or less. Beginning counts correspond to the contamination level present in the system after installing the test pump. End contamination levels were those observed after subjecting the pump to the break-in procedure with the system filters remaining in the system.

| | | | Number of Particles Per Millilitre Greater Than the Indicated Micrometre Size | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | > 8 um | | > 10 um | | > 20 um | | > 30 um | | > 40 um | |
| | Pump Code | FPI Tag # | Beg | End | Beg | End | Beg | End | Beg | End | Beg | End |
| $M_3$ | 16283 | 175 | 136 | 45 | 80 | 29 | 20 | 7 | 11 | 3 | 7 | 2 |
| | 63661 | 173 | 59 | 92 | 31 | 45 | 5 | 8 | 1.4 | 4.4 | .8 | 3 |
| | 18103 | 177 | 23 | 76 | 9 | 43 | 1.2 | 13 | .6 | 6 | .4 | 4 |
| | 17453 | 176 | 146 | 67 | 92 | 40 | 15 | 7 | 4 | 1.6 | 2 | .6 |
| $M_2$ | 05585 | 174 | 39 | 48 | 18 | 32 | 4 | 5 | 2 | 1.2 | 1.4 | .6 |
| | 56941 | 185 | 79 | 17 | 51 | 7 | 6 | 2.4 | 2 | .8 | 1 | .4 |
| | 16439 | 186 | 21 | 114 | 11 | 81 | 3 | 25 | 2 | 11 | .8 | 8 |
| | 11458 | 187 | 90 | 78 | 62 | 50 | 12 | 11 | 6 | 4 | 4 | 2 |
| $M_1$ | 57740 | 178 | 57 | 86 | 26 | 52 | 7 | 12 | 3 | 5 | 1.2 | 1.4 |
| | 84378 | 179 | 105 | 60 | 50 | 40 | 5 | 6 | 2 | 1.4 | .8 | .4 |
| | 25331 | 180 | 69 | 558 | 44 | 232 | 8 | 16 | 3 | 4 | 1.2 | .6 |
| | 12566 | 181 | 40 | 90 | 34 | 60 | 9 | 20 | 3 | 9 | 2 | 4 |

## 1.8.1 TABULATED CONTAMINATION DATA

### PARTICLE COUNT RESULTS OF THE CONTAMINATED FLUID BREAK-IN TEST

AC Fine Test Dust was added to the system fluid to obtain a contamination level of 1500 + 250 particles per millilitre greater than 10 micrometres prior to break-in testing. Beginning levels were observed immediately following installation of test pump and ending levels followed conclusion of break-in procedure. System filters remained out of the circuit for the contaminated break-in tests.

| | | | Number of Particles Per Millilitre Greater Than the Indicated Micrometre Size | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 8 um | | 10 um | | 20 um | | 30 um | | 40 um | |
| | Pump Code | FPI Tag # | Beg | End | Beg | End | Beg | End | Beg | End | Beg | End |
| $M_3$ | 17983 | 228 | 3958 | 5090 | 1596 | 1829 | 111 | 70 | 18 | 6 | 5 | 2 |
| $M_3$ | 08158 | 229 | 4968 | 5910 | 1716 | 2508 | 103 | 68 | 22 | 17 | 7 | 5 |
| $M_2$ | 18593 | 188 | 3984 | 6686 | 1456 | 2463 | 125 | 209 | 18 | 49 | 3 | 16 |
| $M_2$ | 64952 | 189 | [illegible]380 | 4330 | 1562 | 1997 | 193 | 122 | 44 | 11 | 16 | 2.5 |
| $M_1$ | 44947 | 183 | 4377 | 4508 | 1264 | 1203 | 89 | 26 | 30 | 4 | 11 | 2 |
| $M_1$ | 58678 | 182 | 5382 | 5705 | 1538 | 1612 | 92 | 62 | 20 | 10 | 5 | 3 |

## 1.8.1 TABULATED CONTAMINATION DATA

### BEGINNING AND ENDING PARTICLE COUNT RESULTS OF THE ROLL-OFF CLEANLINESS LEVEL TEST FOR THE GEAR PUMPS BROKEN-IN ON CLEAN FLUID

Results below are fluid contamination levels observed at the beginning and end of the roll-orr cleanliness test. Roll-off cleanliness then is the amount of contamination that a standard production pump as received from the manufacturer adds to the hydraulic system following installation and running. System fluid was initially cleaned up to a level of 100 particles per millilitre greater than ten micrometres of less prior to installing the test pump. Beginning counts correspond to the fluid contamination level immediately after installing the pump and end counts follow twenty minutes of pump operation unloaded with the filters out of the system. Total system fluid volume was measured and equaled 25 gallons.

The procedure reported above was developed by MSOE. At a later date, following completion of this phase of data collection, the Society of Automotive Engineers introduced a draft standard J1227 for determining roll-off cleanliness of hydraulic components. The procedure outlined in SAE J1227 is the same as that utilized here except with a fluid viscosity of manufacturer's recommended minimum as called out in SAE J1227.

Number of Particles Per Millilitre Greater Than the Indicated Micrometre Size

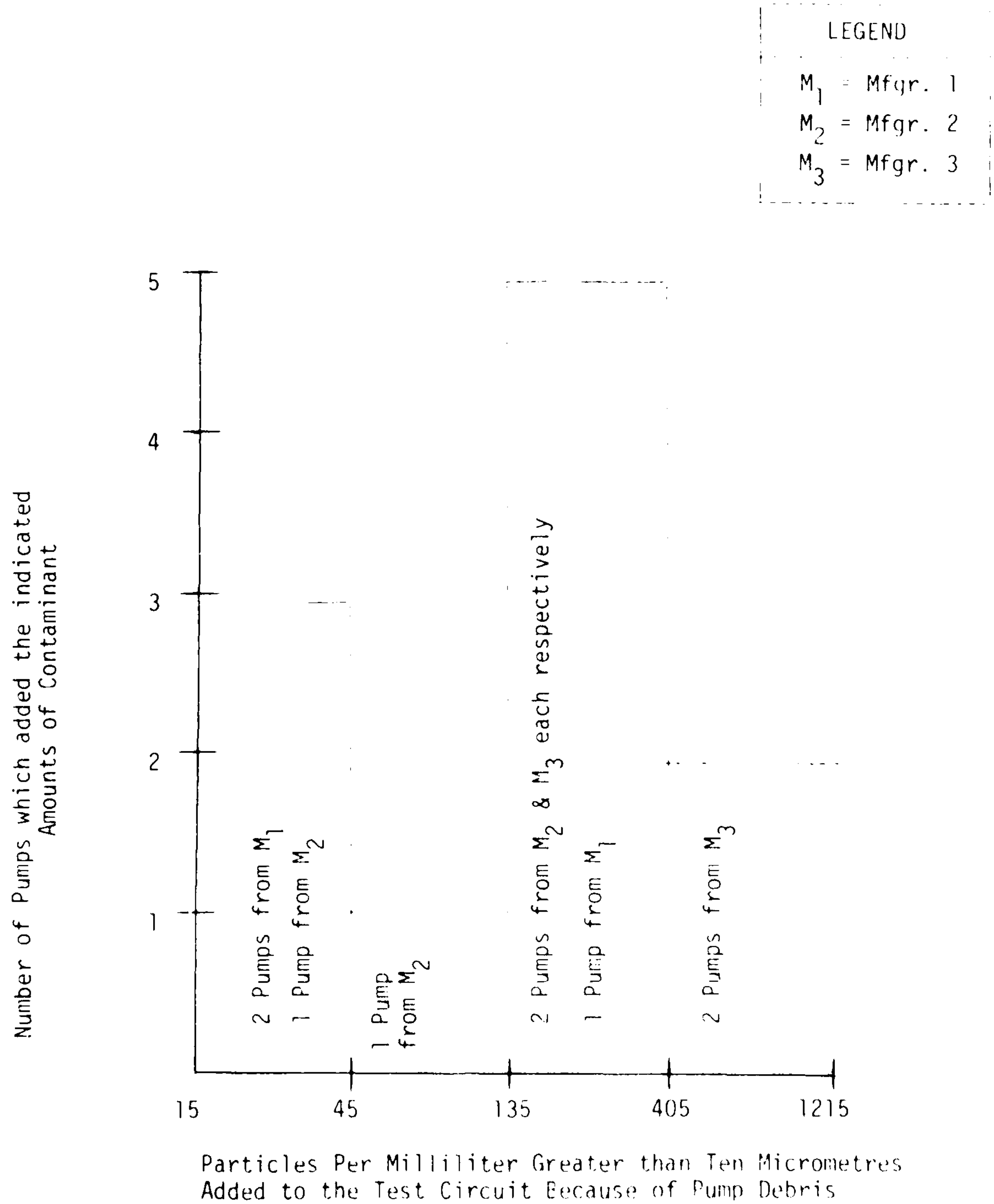
| | Pump Code # | FPI Tag # | 8 um Beg | 8 um End | 8 um Inc | 10 um Beg | 10 um End | 10 um Inc | 20 um Beg | 20 um End | 20 um Inc | 30 um Beg | 30 um End | 30 um Inc | 40 um Beg | 40 um End | 40 um Inc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $M_3$ | 10231 | 175 | 163 | 2243 | 2080 | 70 | 1040 | 970 | 19 | 106 | 87 | 9 | 21 | 12 | 5 | 6 | 1 |
| | 63661 | 173 | 45 | 2612 | 2567 | 29 | 1152 | 1123 | 7 | 120 | 113 | 3 | 37 | 24 | 2 | 10 | 8 |
| | 18103 | 177 | 92 | 524 | 432 | 45 | 251 | 206 | 8 | 44 | 36 | 4.4 | 9 | 4.6 | 3 | 3 | 0 |
| | 17453 | 176 | 76 | 376 | 300 | 43 | 192 | 149 | 13 | 40 | 27 | 6 | 14 | 8 | 4 | 6 | 2 |
| $M_2$ | 05585 | 184 | 67 | 481 | 414 | 40 | 211 | 171 | 7 | 26 | 19 | 2 | 8 | 6 | 6 | 4 | 3.4 |
| | 56941 | 185 | 48 | 291 | 243 | 32 | 172 | 140 | 5 | 25 | 20 | 1.2 | 6 | 4.8 | .6 | 2 | 1.4 |
| | 16439 | 186 | 17 | 228 | 211 | 7 | 126 | 119 | 2.4 | 23 | 21.5 | 1 | 9 | 8 | .4 | 3.4 | 3 |
| | 11458 | 187 | 114 | 200 | 86 | 81 | 100 | 19 | 25 | *14 | 11 | 11 | 3 | *8 | 8 | 1 | *7 |
| $M_1$ | 57740 | 178 | 78 | 836 | 758 | 50 | 370 | 320 | 11 | 33 | 22 | 4 | 8 | 4 | 2 | 2 | 0 |
| | 84378 | 179 | 86 | 184 | 98 | 52 | 94 | 42 | 12 | 16 | 4 | 5 | 6 | 1 | 1.4 | 2 | .6 |
| | 25331 | 180 | 60 | 147 | 87 | 40 | 55 | 15 | 5.6 | 6.2 | .6 | 1.4 | .8 | .6 | .4 | .4 | 0 |
| | 12566 | | Oil sample results were erroneous | | | | | | | | | | | | | | |

* Indicates that the oil was cleaner at the end of the test than at the beginning.

1.8.2 CONTAMINATION GRAPHICAL SUMMARY

HISTOGRAM OF ROLL-OFF CLEANLINESS LEVEL TEST
RESULTS OF 12 GEAR PUMPS BROKEN IN ON CLEAN OIL

Note: The data from one pump of Mfgr. 1 indicated that the contamination level decreased from the beginning to the end of the Roll-Off Cleanliness Level Test - that data is omitted from this graph.



## 1.9 Summary

### 1.9.1 Operational and Technical Problems

During the course of this test program certain operational and technical problems were incurred which are listed below.

1. Electrical interfacing of the data acquisition system with the hydraulic system. Because of "electrical noise" in the laboratory from several sources, special cabling and shielding had to be used between the transducer amplifiers and the data acquisition system to insure accurate signal transmission. Also power line fluctuations caused problems with the data acquisition system until an isolation transformer was installed.

2. Triggering levels in the flowmeter calibration fixture were found to be very nonrepeatable when the magnetic reed switches and photo-optic micro-switches were investigated, so the fiber-optic system was developed.

3. Several ideas were investigated in the development of the torque shaft calibration fixture and found to be inadequate; the pulleys, cables, and weight system didn't work because of bearing lockup. Calibration of the air-cylinders revealed that they were non-linear. Calibration of a 300 lb. load cell at 70 lbs. full scale didn't work because of non-repeatability.

4. During the test phase, it was found that there was a calibration shift in the torque shaft due to a thermal problem because it was calibrated at the start of the test when it was cold and checked at the end of the test when it was warm. A thermocouple was mounted on the torque shaft housing to monitor and record temperature rise versus time for the remaining untested pumps. An equation was developed to correct torque shaft calibration due to temperature rise. The correction factor was then used to correct the torque valves on all eighteen pumps.

Figure 1.9.1

PROGRAM STATUS

| Current Status Laboratory Phase | Contamination Level of Fluid during Endurance Test | Type of Endurance Test Method | Pump Manufacturer and Number of Samples | | |
|---|---|---|---|---|---|
| | | | Mfg. 1 | Mfg. 2 | Mfg. 3 |
| Complete | Clean (Fewer than 100 particles per ml greater than 10 u) | OSU P-4 High Cycle Rate Test | 1 | 1 | 1 |
| Complete | Dirty (about 1500 particles per ml greater than 10 u) | OSU P-4 High Cycle Rate Test | 1 | 1 | 1 |
| In Progress | Dirty (about 1000 particles per ml greater than 10 u) | OSU P-4 High Cycle Rate Test | 1 | 1 | 1 |
| Planned | Dirty (about 1000 particles per ml greater than 10 u) | MIL-P-52675 | 1 | 1 | 1 |

### 1.9.2 Conclusions

1. Currently no industry norms exists for the contamination level of production test stands and the roll off cleanliness level of gear pumps.

2. A buyer of pumps may gain some insight into a manufacturers roll-off cleanliness level merely by requesting receiving and analyzing an oil sample from his test stand. At this time, it is impossible to state that break-in with contaminated oil is, of and by itself detrimental to the life expectancy of a particular pump. The results, however, do clearly indicate strong correlation between test stand contamination level and roll off cleanliness. That is, the manufacturer with the dirtiest test stand oil samples and pumps which contributed the most amount of dirt added to the MSOE system.

3. There was no measurable benefit or liability to the contaminated break-in however, effects of contaminated break-in upon life expectancy have yet to be evaluated.

4. Changes in overall efficiency in the first few hours is caused primarily by changes in mechanical efficiency and not the volumetric efficiency.

5. Manufacturer No. 1 had the least amount of overall efficiency change, however, conversations with manufacturer No. 1 revealed that there may be up to ten hours of running on each pump before they were tested by FPI MSOE.

6. Although different break-in procedures were not investigated, the pressure time profile used in this program is based on current industry practice, and it must be concluded that it is a sufficient process if followed by a few hours of steady state high pressure running. Some efficiencies were still changing after two hours, but these were not significant. The results indicate that pumps with short running times do indeed undergo changes in performance.

7. Any industry standard which aims at acquiring power conversion data to be used in the market place should contain a requirement that the pump be broken-in and then run in at high pressure for a total of about three hours. There are indeed changes taking place inside the pump and they appear to settle down after that period of time. Premature measurement of power conversion data may result in a difference in overall efficiency by as much as five percent, a difference which in most cases results in an improvement in the pumps' quality.

### 1.9.3 Program Status

Program activity concurrent with the submission date of this report is in the High Cycle Rate Durability Testing phase as shown in figure 1.1.1 page 2. No preliminary conclusion can be drawn at this time since the data collected is presently being processed by the computer. Results of the durability and endurance testing phases will be available in part III of this report to be published at a later date.

A review of the program effort by MERADCOM over the course of testing has resulted in minor technical changes at their request in the life test phases. Since these differ from those contained in the MSOE proposal entitled "A Proposal To Conduct A Comparative Study of Accelerated Life Test Methods on Hydraulic Fluid Power Gear Pumps" dated 28 August, 1978, a revised block diagram of the life test phases and current status is presented in figure 1.9.1 page

1.9.4 Recommendations

The results of this program effort will serve as valuable technical inputs to future revisions of NFPA T3.9.17 Pump and Motor Test Procedure and MIL-P-52675 Military Specifications Pumps, Hydraulic, Oil, Fixed Displacement. Viable standards in cognizance with the needs of the US Army and the Fluid Power Industry will then be readily available and insure the advancement of the "state-of-the-art" of Fluid Power Technology. To this end, the following recommendations are made based upon the knowledge and experience we have gained in the course of this program.

1. Since both of the previously cited standards apply to both gear and vane type pumps, the MSOE proposed additional effort shown in figure 1.1.1 page 2 and outlined in "Proposed Modification to Include Vane Pump Testing" dated 13 March, 1979 be pursued.
2. Develop a program for the 6 gear pumps from the Break-In program using contaminated oil to determine their expected lives.
3. Direct efforts to promulgate and implement SAEJ1227 dealing with the evaluation of roll off cleanliness of hydraulic components.
4. Industrial standards which the US Army expects to reference in it's procurement procedures should contain the break-in procedure reported herein.
5. Speed droop during the cyclic portion of the break-in is difficult to control without expensive feedback equipment. Any standard should allow for a 10% drop-off in speed in going from no-load to full-load. This is easy to achieve with an open-loop pump drive, corrections for this can be handled mathematically.
6. Because there are a number of reasons for speed variation during the two-hour run, any standard should allow for a ± 4% (2 standard deviations, 95% confidence) speed variation, since flow can be corrected mathematically.
7. Because there are a number of reasons for pressure variations during the two-hour run, any standard should allow for a ± 2 (2 standard deviations, 95% confidence) pressure variation, since torque can be corrected mathematically.

## PART 2.0

## PROGRAM SUPPORT

Part 2 details the support work preceding the laboratory program specifically: Development of the laboratory break-in procedure and traceability, calibration, and verification of the measurement system. The appendix contains the data for part 2. Since adequate industrial standards already existed in the area of contamination analysis and reporting, these standards were implemented and are considered sufficient. The standards implemented were:

1. NFPA T2.9.1-1972, ANSI B93.19-1972 Method of Extracting Fluid Samples from the Lines of Operating Hydraulic Fluid Power System for Particulate Contamination Analysis.
2. NFPA T2.9.2-1972, ANSI B93.20-1972 Procedure for Qualifying and Controlling Cleaning Methods for Hydraulic Fluid Power Fluid Sample Containers.
3. NFPA T2.9.6-1972, ANSI B93.28-1972 Method for Calibration of Liquid Automatic Particle Counters Using AC Fine Test Dust.
4. NFPA T2.9.3-1973, ANSI B93.30-1973 Method of Reporting Contamination Analysis Data of Hydraulic Fluid Power Systems.

## 2.1 Literature Search Results

### 2.1.1 Introduction

A literature search was conducted by surveying various technical sources of information such as universities and professional technical societies to determine if any work has been previously done in areas related to this contract effort. This section contains a listing of the technical papers compiled during the courses of this contract.

### 2.1.2 Contamination Papers

1. A New Theory for the Contaminant Sensitivity of Fluid Power Pumps OSU paper no. P72-CC-6.
2. Analysis of Hydraulic Fluid for Chlorine Containing Contaminants ASLE transactions volume 30, 10, 506-509.
3. Contaminated Lubricants and Tapered Roller Bearing Wear ASLE transactions volume 20, 2, 97-107.
4. Determining Contamination Levels in Hydraulic Systems ASLE 24th annual meeting May 5-9, 1969.
5. Lubricant Contaminants and Their Effect on Bearing Performance SAE paper no. 750583.
6. Pump Contamination Sensitivity Versus Operating Pressure OSU paper no. P74-43.
7. Speed and Viscosity Effects on the Contamination Sensitivity of Hydraulic Pumps OSU paper no. P76-4.
8. The Effect of Contaminated Lubricants Upon Tapered Roller Bearing Wear OSU paper no. P74-57.
9. The Evaluation of the Air Enteraining Tendency of Fluids.
10. Verification of the Pump Contaminant Wear Theory Part 1. OSU paper no. P76-5.

### 2.1.3 Filtration Papers

11. Choosing a Full Flow Filter Element for Industrial Hydraulic Fluid Power Systems ASLE 21st annual meeting May 2-5, 1966.
12. Suction and Pressure Line Filtration; Proper Selection, Installation, and Maintanence. ASLE 21st annual meeting May 2-5, 1966.

### 2.1.4 Instrumentation Papers

13. Application of Infrared Spectrometric Techniques to the Quantitative Analysis of Hydraulic Fluids ASLE transactions volume 13, 99-104.
14. Data Acquisition Techniques for Fluid Power Systems OSU paper no. P73-SP-5.
15. Frequency Output Pressure Sensors Based on an Application of Surface Acoustic Wave Technology. SAE paper no. 760093.

16. Some Applications of the Scanning Electron Microscope in Wear Studies ASLE transactions volume 31, 10, 521-529.

17. The Answer to Low Cost Data Acquisition OSU paper no. P73-RQ-3.

2.1.5 Wear Papers

18. Analysis of Tapered Roller Bearing Damage ASM report no. C7-11.1.

19. Applied Wear Analysis; A Review of Some Performance and Life Tests on Hydraulic Pumps OSU paper no. P71-SP-5.

20. Bearing Bronze Wear in Hydraulic and Lubricating Fluid Environments ASLE Transactions volume 28, 408-411.

21. Effects of Rear Axle Lubricants on the Fatigue Life of Tapered Roller Bearings SAE paper no. 760329.

22. Friction, Lubrication, and Wear in Machinery U.S. Dept. of Commerce NTIS AD-749 086.

23. Ideas and Hypotheses on Plain Bearing Failures ASME paper no. 77DGP-13

24. Relative Wear Resistance of Metals Under Hydroabrasive Wear U.S. Dept. of Commerce NTIS AD-747-668.

25. Tribological Interaction Between Piston and Cylinder of Model High Pressure Hydraulic Pump. ASLE transactions volume, 18, 1, 21-30.

2.1.6 Miscellaneous Papers

26. Compiled ASLE Transactions Volume 30, Number 3 July, 1977.

27. Compatibility of Hydraulic Systems Material ASLE transactions volume 32, 6, 299-305.

28. Selecting and Installing the Hydraulic Pump. ASLE 19th annual meeting May 26-28, 1964.

29. Test Techniques for the Evaluation of Lubrication Effects on Axle Break-In Temperature. SAE paper no. 760327.

2.1.7 Conclusions

The above papers were reviewed and it was determined that little work has been done in the areas of universal break-in procedures, break-in using contaminated fluid and long term effects of contaminated fluid on the life of hydraulic pumps.

## 2.2 Break-In Procedure Survey Summary

### 2.2.1 Introduction

In course of this program, 32 manufacturers were surveyed by mail to determine the break-in procedures they used in producing gear pumps. The respective manufacturers surveyed were selected from those listed as producing gear pumps in the Hydraulics and Pneumatics magazine Designers Guide to Fluid Power Products. The results of this survey were later analyzed and served as the basis in developing a general procedure as followed in this program. Survey results are contained in appendix F.

### 2.2.2 Results

Survey results indicated considerable agreement in the break-in procedure used prior to qualification testing. Most companies (61.5%) reported having a criterion for determining the pump break-in point. The procedures were based on laboratory studies (69.2%) and experience with the product (76.9%) in most returns.

In (78.6%) of the returns, the break-in cycle was conducted at constant speed. The constant speed selected was 1800 rpm in 4 cases, rated speed in 4 cases, and some other speed in the remaining 2 cases. It was observed in the majority of responses that constant speed was established quickly but some companies increased the speed slowly or even incrementally to that required for break-in. Outlet pump pressure was varied in (69.2%) of the responses. The procedure ranged from continuously variable to "spiked". In most cases, pressure was increased in steps with 3 as a minimum to 7 maximum. The respondents unanimously reported not using a constant torque condition.

Total elapsed time of the procedure ranged from 10 sec. to 9 min. Typically the procedure was concluded by evaluating flow at a particular speed and load pressure. The unit was accepted if it met specifications or historical limits.

In 3 of the 13 returns, companies reported using different procedures for individual pump designs. Otherwise, the indication is, that manufacturers applied a particular procedure to their entire pump product line.

The following is a summary of other information also reported in the break-in procedure survey:

Fluid: Mobil 523
A.T.F. Type F
Texaco Rando [illegible] Anti Wear
SAE 10W & Anti Wear
SAE 10W
Mobile DTE 26
Dexron

Contamination: [illegible] mg/100 ml max.
Water Content: 0.1 , 0.001

In addition to requesting specific information concerning the break-in procedure, opportunity was provided to survey the condition of fluid used in production test stands. Five companies agreed to submit oil samples and a result summary appears on the following page.

The contamination levels were significantly higher than expected based upon our experience with those we have normally encountered in hydraulic systems. With respect to water content, low levels were observed in all samples tested.

Since no standards exist for atomic absorption, conclusions drawn are intuitive. Of the metallic ions analyzed, copper and lead were observed in high concentrations when compared to the other elements. This is not surprising since these elements normally comprise bearing materials. The indication is that portions of the pumps comprised of bearing materials are seating or wearing in.

While high concentrations of zinc were reported in all cases, this is an anti-wear additive found in many commercial hydraulic oils.

AD-A152 248 INVESTIGATION INTO HYDRAULIC GEAR PUMP EFFICIENCIES DURING THE FIRST FEW..(U) MILWAUKEE SCHOOL OF ENGINEERING WI FLUID POWER INST 12 NOV 79 2/3

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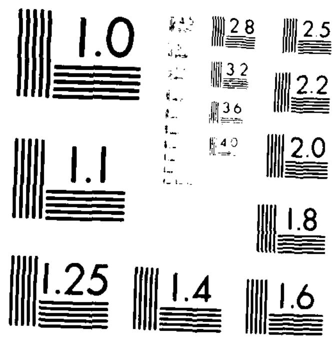



MICROCOPY RESOLUTION TEST CHART

## PRODUCTION TEST STAND OIL SAMPLE RESULTS

The range and average are the results of a total of five Manufacture's oil samples. Each of the three individual manufacturer's results are presented also. Oil samples were submitted by respondees to the gear pump break-in procedure survey.

TABLE 2.2.1

CONTAMINATION ANALYSIS RESULTS SUMMARY

| | Particles Per Millilitre Greater Than The Indicated Micrometre Size | | | | | Water Content % By Volume |
|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | |
| Range | 427-17081 | 64-2073 | 8-471 | 4.4-168 | 2.8-74 | .008-.016 |
| Average | 6268 | 556 | 135 | 53 | 25 | .0112 |
| $M_1$ | 1135 | 168 | 48 | 18.2 | 8.7 | 0.013 |
| $M_2$ | 4156 | 400 | 128 | 64 | 35 | 0.01 |
| $M_3$ | 17081 | 2073 | 471 | 168 | 74 | 0.008 |

$M_1$ Mfgr. 1

$M_2$ Mfgr. 2

$M_3$ Mfgr. 3

## PRODUCTION TEST STAND OIL SAMPLE RESULTS

The range and average are the results of a total of five manufacturer's oil samples. Each of the three individual manufacturer's results are presented also. Oil samples were submitted by respondees to the gear pump break-in procedure survey.

TABLE 2.2.2

ATOMIC ABSORPTION ANALYSIS RESULTS SUMMARY

| | Concentration Metallic Ions ppm by Weight | | | | | |
|---|---|---|---|---|---|---|
| | Al | Cu | Fe | Pb | Zn | Si |
| Range | .1-9 | .5-56 | .5-14 | 1.5-97 | 400-650 | 2-6. |
| Average | 2.58 | 27.50 | 6.10 | 42.30 | 534 | 4.40 |
| $M_1$ | 9 | 56 | 5 | 65 | 650 | 6 |
| $M_2$ | 0.1 | 39 | 14 | 97 | 500 | 5 |
| $M_3$ | 0.3 | 30 | 8 | 34 | 500 | 4 |

$M_1$ = Mfgr. 1

$M_2$ = Mfgr 2

$M_3$ = Mfgr. 3

## 2.3 Assessing Data Accuracy in Fluid Power Testing

### 2.3.1 Justification for Measurement Accuracy

The basic motivation for examining measurement accuracy is the realization that the results of an experiment are no better than the measurements made. The purpose of collecting the data (measurements) is to provide a data base for action or decision. This leads to additional pressures to assess measurement accuracy, however, accuracy should not be any greater than that which is needed to decide on a course of action with reasonable confidence.

The current climate of social and legal influences as represented by the courts, the legislatures, and consumer advocacy groups are demanding better and safer products, so it is necessary that we have more reliable test results. Decisions can then be made regarding the quality of the product under test and those decisions can be made with reasonable confidence.

The accuracy and validity of any conclusions formed as the result of experimental work depends upon the validity of the various measurements made during the experiment. Since the measurement process basically involves comparing an unknown quantity to a known one, there exists a need for universally recognized and accepted standards. Instruments used in the laboratory and for that matter commerce, are calibrated against a standard. In the United States, the National Bureau of Standards (NBS) serves as the source of universally recognized standards. Through various agencies, these standards find wide acceptance in commerce. For example, state agencies routinely inspect supermarket weight scales and service station gas pumps for accuracy traceable to NBS. However, evidence exists that maximum use of traceability to NBS is lacking in some Fluid Power testing laboratories. There exists a potential for growth in this area. Currently the National Fluid Power Association is in the process of re-establishing a measurements project group and is including traceability requirements in the scope of its work.

However, the existence of standards for calibration is not totally sufficient. In calibrating instruments, there exists a difference between an instrument's accuracy and its precision. Accuracy refers to confidence in close correlation between the same measurements in one location and another, or between a measurement and a recognized standard all with the same result. Precision, on the other hand, implies careful measurements under controlled conditions which can be repeated again and again. Precision then is related to confidence in successive measurements with the same equipment and operating conditions. It is entirely possible to have precision without accuracy. Ideally an instrument should possess both attributes and the purpose of calibration is to verify this. More will be said on this subject later.

### 2.3.2 Sources of Errors in Measurement

While instrument calibration is a prerequisite for accurate measurements, other factors do influence the results. A brief review of some of these is appropriate but we will not dwell on these.

Certainly the type of measurement made will affect results. There are basically three types: A primary measurement is one that can be made directly, with no translation of the measured property. An example of this is the measurement of linear dimensions with a ruler. A secondary measurement involves one translation. The measured quantity may not be made directly. An example of a secondary measurement is a Bourdon tube pressure gauge. Pressure is translated into a scale movement. Tertiary measurements involve two translations. A typical example is the measurement of rotational shaft speed using an electric tachometer. In this case, speed is translated to voltage and voltage is translated to a scale movement on the meter readout. It is obvious the possibilities for error increase with the type of measurement made from primary to tertiary.

In general, it is possible to classify measurement errors into four types: observation errors (human error made by the observer in reading a scale and pointer), translation errors (instrument originated, for example inertia and hysteresis effects), signal transmission errors (such as a voltage drop along the wires between transducer and readout), and instrument location errors (an example of which is ignoring an elevation difference between pressure gauge and tap). In application, other factors as the test procedure used and degree of control of parameters in the experiment will effect the final test results and therefore the conclusions drawn. These will not be dealt with further here but are included since acknowledgement of their existence is important.

### 2.3.3 Assessment of Measurement Accuracy

As we have just observed, there are several sources of error possible in physical measurements. It is usually desireable to distinquish between systematic errors and random errors in calibration processes. First we shall define what is meant by systematic errors.

Systematic errors are those which remain constant through all repetitions of the measurement process and produce a drift, trend, or other predictable pattern among repeated measurement results.

They are not ordinarily evident from an examination of the data but are detectable by making comparisons to a standard or with results from other processes or methods.

Random errors on the other hand can be defined as non-systematic and are exhibited in repeated measurements of the same quantity varying in an irregular manner without a discernable or predictable pattern.

In the calibration procedure to be defined later, these errors are taken into consideration. The important point in considering these errors though, is to use them as a criterion in instrument selection.

Typically, Fluid Power standards require instruments to be selected which are accurate within $\pm 2\%$. This is somewhat nebulous because a percentage is a ratio of two numbers, and if the standard does not specify the source of both there is no way to implement the criterion. In 1973, the M.S.O.E. Fluid Power Institute surveyed over 180 industrial Fluid Power Labs throughout the U.S. and reached several revealing conclusions.

First, there is no way to effectively prove or disprove a given accuracy claim, and second, even though different labs used similar instruments, their accuracy claims differed by as much as 10%. Today's standards explain the test procedures, and sometimes spell out the circuit and exact equipment. They also show how data is to be presented but they offer no assistance in assessing the level of accuracy achieved or how to arrive at the required accuracy level.

As a minimum, calibration must prove the instrument to be repeatable to a degree less than the end accuracy required and in a cost effective manner. The instrument manufacturers and metrologists have developed calibration standards which are necessary to evaluate intrinsic errors of the instrument only. The instrument users have developed test procedures based upon Fluid Power needs, and in them have stated the end accuracy needed in the measurements specified. As a result, the laboratory is required to bridge the gap between the end accuracy specification and the instrument manufacturer's specifications by engaging in what must be construed as the black art of testing. What is needed is a procedure which addresses the evaluation of instrument accuracy through calibration prior to use in testing.

When this procedure is developed and accepted, it should be incorporated in individual test standards since each carries its own accuracy and instrumentation needs based upon the nature and use of the physical quantities to be measured. But before further progress can be achieved in developing this procedure, a controversy which currently exists in the standards arena must be reconciled. This controversy relates to the use of percent of reading versus percent of maximum measured value in assessing measurement accuracy. This leads to a logical question, what is the difference. Let me explain.

Percent of reading requires that all measurement be within the stated accuracy required and necessitates that the instrument be changed as the measured value rises and falls. Its only advantages are that it prevents an overranged instrument from being used near the bottom of its scale and it is easy to specify. But these advantages are overshadowed by the impracticality of the concept. In many tests, the instrument may not be conveniently changed particularly when dynamic measurements are being made over a large range of values. Also, one has to pose the question, why is one ten times more interested in say the flow out of a pump when it is operating at 10% of rated speed than one is when at full rated speed? It is hard to conceive of a situation where one would be.

Percent of maximum measured value on the other hand is practical, economical, and represents current industrial practice. This concept however is easy to implement but difficult to document.

From a knowledge of the component to be tested, the nature of the test, the maximum value of say, flow, is anticipated and a flow meter is selected. The selection criterion is based on formulas which use instrument design features, calibration data and accuracy needs. Once selected, the flow meter is not changed throughout the test regardless of how low the flow may go. We advocate adoption of percent of a maximum measured value as a data accuracy requirement. Again each test standard though, must have its own accuracy requirements and instrumentation needs. Each must be considered as an individual entity. Although this sounds complicated, it reflects what is being done in industry today and it's not all that complex once you get into it.

### 2.3.4 Proposed Approach to Assessing Measurement Accuracy

The approach we are proposing for assessing measurement accuracy bridges the gap between instrument manufacturers' specifications and the end accuracy needed in the laboratory measurement process. We are proposing a procedure for instrument calibration which develops a mathematical model and then assesses the amount of calibration error. The total error arrived at in this procedure is the sum of the reference standard error, calibration error, and readability error. While metrologists may argue about how to classify these errors as either systematic or random, we are proposing to add them linearly but further work is obviously needed. Details of the procedure may be found in appendix G but let us now review some of the general concepts.

The first error we are concerned with is the error of the reference standard used in calibrating the working instrument. This error is easily obtained either from the manufacturer or certifying agency who provided certification traceable to N.B.S. on the standard. The reference standard error is usually the smallest of the three errors we are concerned with.

The calibration error is, as its name implies, determined through a calibration comparison with the reference standard. This comparison is made at each of 10 equal increments of the maximum value of measurement expected in data collection. It should be recognized that only if a number of repeated trials at each increment are conducted, only then can a trend be established and the existence of any difficulties noted. Therefore five trials for each measurement increment are performed. If a working instrument is known to be subject to hysterisis effects the five trials should be performed for both increasing and decreasing values at each increment.

Having collected the necessary calibration data, the calibration error may now be determined using one of the four following mathematical models. The first order model makes direct use of the indicated value of a readout device without resorting to any corrections. In other words, the instrument and readout device are the model.

A second order mathematical model assumes that the indicated value is related to the actual value of a physical variable and any influencing environmental factors through a formula of the form;

$$\text{Actual Value} = b_0 + \sum_{k=1}^{n} b_K \times (\text{indicated value})^K + \sum_{i=1}^{n} a_i \; f(E_i)$$

where $E_i$ is one of $n$ influencing environmental factors, $f(E_i)$ is the functional manner in which $E_i$ affects the measurement of the actual value and $a_i$ is a linear coefficient which affects the degree of effect.

$f(E_i)$ may be determined by any one of the following methods:

1. Use acceptable theories.

2. Use empirical data as measured during controlled experiments during Working Instrument Calibration.

3. Use manufacturer's data, such as, for instance, zero shift due to temperature, or span shift due to viscosity, etc.

4. Ignore Environmental Factors when they are brought into sufficient agreement in the Measurement Situation with the values that existed during the Calibration Situation.

5. Ignore Environmental Factors which are known to have an insignificant influence upon the Indicated Value.

Evaluate $b_0$, $b_i$, and $a_i$ using linear regression on all data from all trials of calibration conducted.

A third order mathematical model makes use of a point to point correction under the assumption that corrections are linear when the indicated values in the measurement situation lie between data points used during the calibration situation.

The fourth order mathematical model accomodates complex mathematical functions which relate the actual value to the indicated value and any influencing factors. It has no specific general form.

The calibration error then, is determined by either first implementing the model or using the data directly to find the differences between the mean value of the 5 trials and each trial value for all calibration increments. The standard deviation of all the differences is then calculated. The calibration error is equal to two times this standard deviation for a 95% confidence level.

The final step before the total measurement error can be evaluated is to ascertain the readability error (RE) in the readout device. Here however, it is necessary to distinguish between analog and digital devices. Of the two types of readout devices, the digital error is most easily determined. Its value is equal to the smallest change in the lease significant digit or the smallest integer change possible for the particular readout.

The readability error for an analog device is calculated by using the following formula:

$$RE = \frac{\text{Value of the Smallest Scale Division}}{(RF_1 \times RF_2 + 2)}$$

where $RF_1$ and $RF_2$ are determined from the properties of the readout device in the following manner. It is assumed that the instrument is equipped with a parallax error minimizing feature.

$RF_1$ is determined by finding the width of the smallest scale division (W) in mm and substituting in the appropriate formula below;

$$RF_1 = 3(1-\epsilon^{0.5-1.1W}) \qquad W > 0.5 \text{ mm}$$

$$RF_1 = 0 \qquad W \leq 0.5 \text{ mm}$$

$RF_2$ is determined in the following fashion. First estimate the width of the pointer to the nearest 0.25 mm in the region on the pointer where the reading is interpreted. Divide the width of the smallest scale division found previously by the pointer width to form the ratio $\alpha$. Calculate $RF_2$ by using the appropriate formula as determined by the value of $\alpha$;

$$RF_2 = 1 - \epsilon^{0.5(1-\alpha)} \qquad \alpha \geq 1.0$$

$$RF_2 = 0 \qquad \alpha \leq 1.0$$

By adopting the procedures set forth in this paper, a practical means is provided for assessing data accuracy. The suitability of an instrument for use in a particular measurement situation may also be determined in a practical manner. If the total error as determined in this procedure does not exceed the accuracy required in the measurement situation, regardless of where in the instrument's range measurements are made, the instrument is considered acceptable for use. Scientific evidence then forms the basis for judging the suitability of instruments instead of rules of thumb for example, do not use an instrument for measurement below 25% of full scale. Any instrument can be used in any portion of its' usuable range if it can be demonstrated that it meets the accuracy requirements.

## 2.4 Pressure Calibration

### 2.4.1 Introduction

The usual method for measuring pressure is by secondary measurement, using a pressure gage to translate pressure into a scale movement or a pressure transducer which translates pressure to a proportional voltage. Hence, accurate calibration is a necessary prerequisite to accurate pressure measurements.

#### 2.4.1.1 Definitions

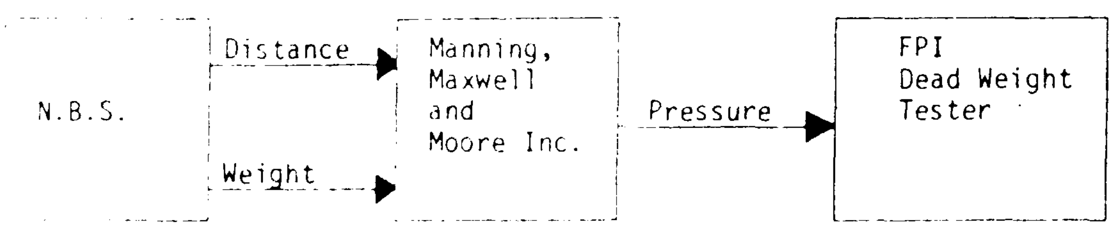
Pressure is defined as force per unit area and is measured either in units consistent with this or in terms of an equivalent head of some standard liquid. When a fluid is at rest, the pressure within it at any one point is omni - directional (Pascal's Principle), but definite directional effects exist within fluids in motion. The main difference between a pressure within a static fluid and a stress within a static solid lies in the fact that the stress will have definite directional effects, while pressure will not. The calibration work described here concerned itself with static liquid pressure.

### 2.4.2 Traceability

Pressure is traceable to N.B.S. thru an Ashcroft dead weight tester type 1305, certificate of accuracy number 2GH-21398 from Manning, Maxwell, and Moore, Inc., Stratford, Conn. dated March 30, 1978. Accuracy is certified to one tenth of one percent.

#### 2.4.2.1 Source Flow Chart

FIGURE 2.4.1



### 2.4.3 Calibration of Working Instrument

#### 2.4.3.1 Working Instrument

Since pressure is force per unit area, one method for obtaining known pressures is to use a device which will impose a known force upon a known cross-sectional area. Such a device is the Ashcroft dead weight tester which serves as our lab reference. It consists of a hydraulic system filled with oil connecting the instrument to be calibrated with a piston in a vertical cylinder, and a [illegible] hand pump and reservoir. Calibrated weights [illegible] to be added to the top of the piston to achieve the desired pressure. Pressure is developed [illegible] the hand pump until the piston floats freely at which point the pressure reached is that as determined by the weights added.

#### 2.4.3.2 Procedure

The transducer was connected to the Ashcroft dead weight tester and electrically to the transducer power supply/signal amplifier. Output from the transducer was also [illegible] on the data acquisition system (DAS). The channel used in calibration was the same as that used during testing.

Prior to calibration, the transducer zero was set and the [illegible] was adjusted to obtain the required gain with the Ashcroft dead weight tester providing a reference source of hydraulic pressure. Pressure was then released and the transducer's zero output was recorded on the data acquisition system.

The calibration procedure followed is described in appendix [illegible]. The maximum expected value of pressure measured was determined and 10 equal increments of that value were used in calibration. The Ashcroft dead weight tester was pumped up to the first increment and the transducer output was recorded by the DAS printer. This was an increasing pressure value. Decreasing pressure readings were obtained with the Ashcroft dead weight tester since it has an internal mechanical piston stop. This feature permits increasing pressure beyond a particular pressure increment with the same weights as required for that increment. The pressure increment may then be approached in the decreasing direction by bleeding off pressure until the weights are floating using the internal needle bleed valve normally used for releasing pressure. The transducer's decreasing pressure value was obtained in this manner. Increasing and decreasing [illegible] were recorded by the DAS and the pressure [illegible] output was then recorded for [illegible] pressure. The above procedure was [illegible] for each successive pressure increment in the range and [illegible] trials at each increment were performed.

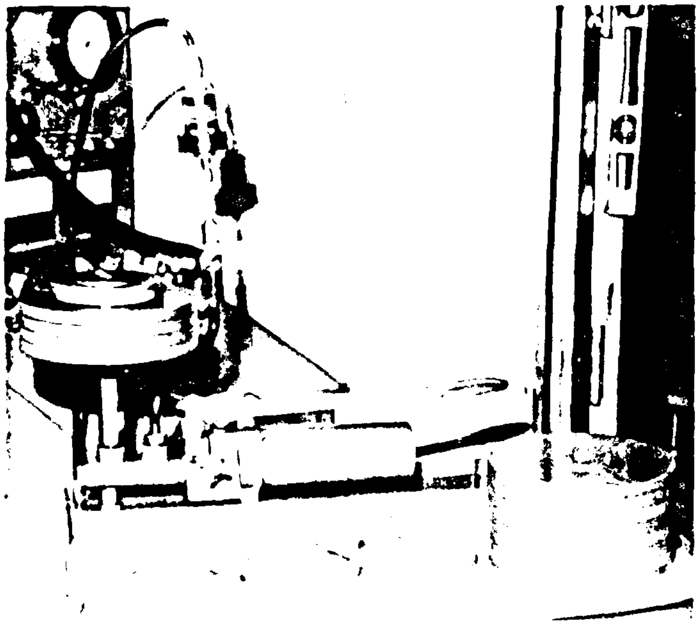


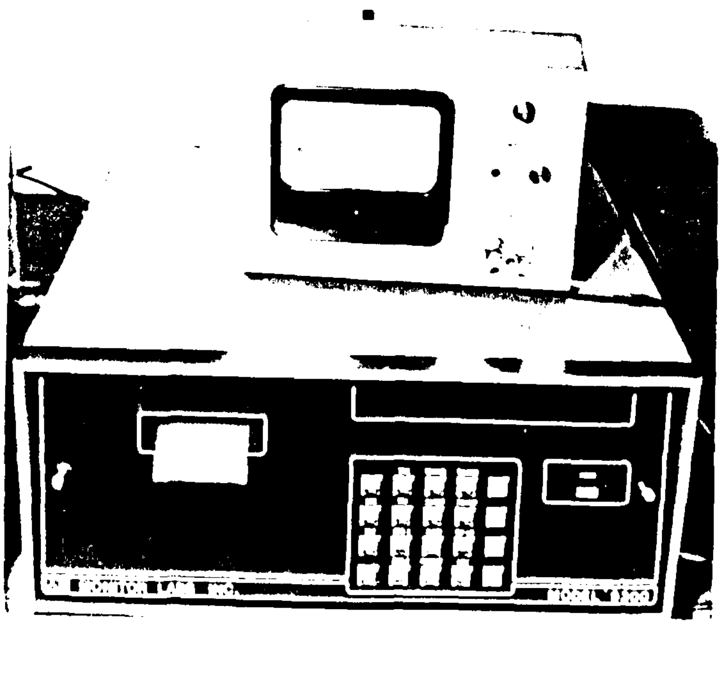
Figure 2.4.2

PRESSURE TRANSDUCER DEAD WEIGHT CALIBRATION

Pressure transducer plumbed to the dead weight tester for calibration. Weights are placed in the piston and the pressure is increased until the piston raises and floats in the cylinder.

[illegible]

[illegible] supply [illegible] voltage.



2.6.3.2 Procedure for Calibration of Lab Reference.

NOTE: In order to establish consistency with the Wisconsin Dept. of Agriculture calibration methods, the displacement volume was calibrated using water.

The problem here was to determine the volume, within the volume calibrator, that corresponded to the upper and lower slots on the flag. Also, to determine the repeatability of the liquid level at which the trigger circuit would fire at both the upper and lower slots.

To test for liquid level repeatability, an upright plexiglass tube with a needle valve shut-off was attached to the side of the volume calibrator.

With the needle valve open, the volume calibrator was filled with water until the upper displacement trigger level (lower slot) was reached and the level detection circuit had triggered. Liquid was drawn up the plastic tube using a vacuum pump. This lowered the liquid level in the volume calibrator to a point below the trigger level. The vacuum in the displacement tube was removed and the needle valve was closed maintaining the height of the water column. The needle valve was opened to allow the liquid level in the plastic tube to fall (liquid level in the volume calibrator rose). When the start signal from the trigger circuit activated, the needle valve was quickly shut off and the liquid level in the plastic tube was marked. This procedure was repeated nine more times. An arbitrary datum, on the plastic tube, was selected and the distance from the datum to each of the ten recorded levels was measured and an average was calculated. The liquid level in the plastic tube was adjusted until it reached the average value of the ten trials, then the needle valve was closed. This was designated as the best estimate of the upper displacement volume level. (Standard deviation of the upper level trigger points was 0.86 cu. in. out of 9333 cu. in.).

The next problem was to determine the net volume between the upper and lower limits. Using the Seraphin buckets, eight 5 gallon measures and one 1 gallon measure totaling 41 gallons were removed from the volume calibrator (the needle valve was closed). This dropped the liquid level below the lower trigger point, meaning that too much was removed. An addition of 2000 c.c. volume of water was put back in to compensate for some of the overdraft. At this point, the trigger was impending but not actually reached. The needle valve was opened and the water level in the plastic tube was allowed to fall

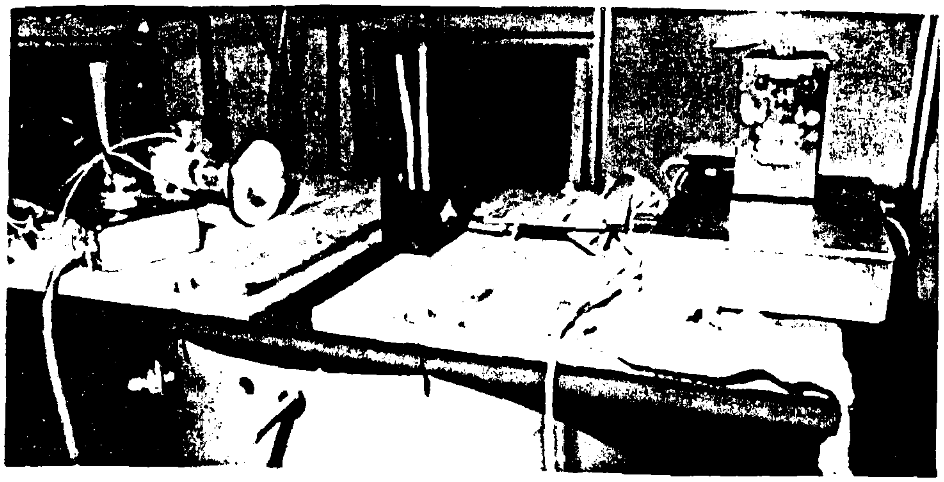


Figure 2.6.4

FLOW RATE CALIBRATION BARREL SENSING SYSTEM

[illegible] was positioned in front of the flag. Immediately [illegible] was the fiber optic sensor. These optical fibers [illegible] photo conductor which controlled the starting [illegible] frequency counters when the slot on the flag [illegible] light through.

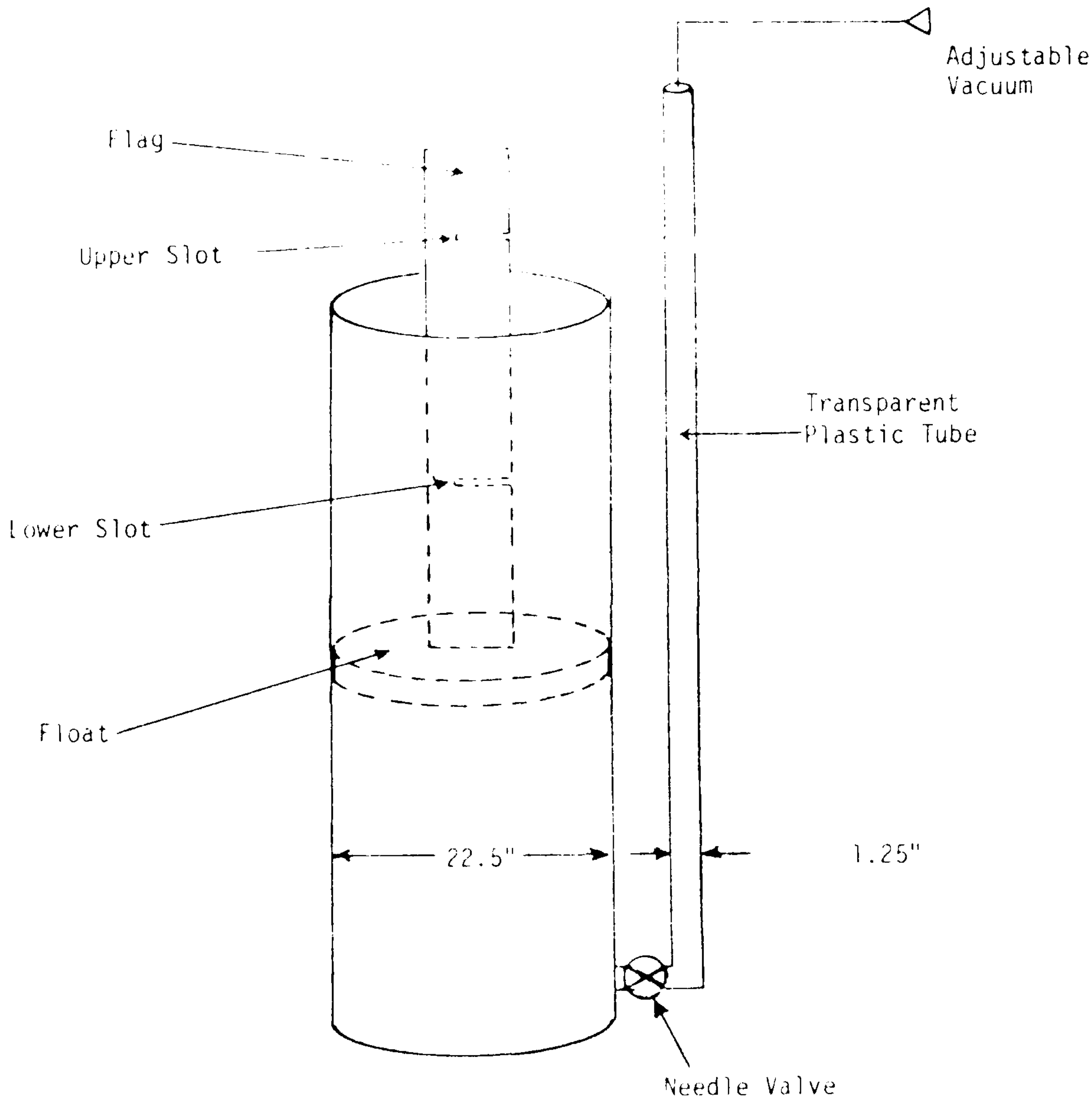



Figure 2.6.[illegible]

FLOW RATE CALIBRATION BARREL

2.6.2.1 Traceability Flow Chart

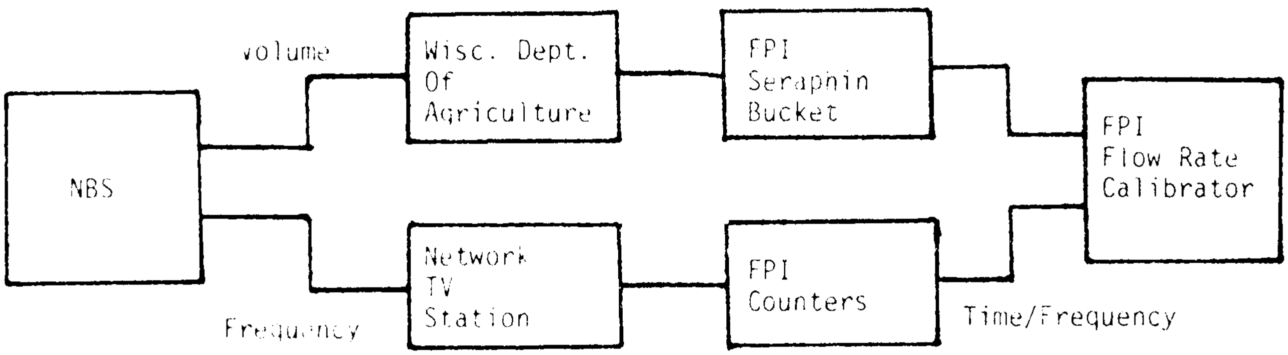



Figure 2.6.2

2.6.3 Calibration of Laboratory Reference

2.6.3.1 Lab Reference - The laboratory reference is a stand-pipe flow rate calibrator. It consists of two 55 gallon drums welded together with the tops cut out in order to make one long container. The lower half conditions the flow, i.e. dampens the momentum forces and straightens the flow pattern. The upper half contains the displacement volume. A float was placed inside the barrels to help define the upper boundary of the liquid level. Also, this float was used to support a flag with horizontal slots. The distance between the upper and lower slots corresponds to the calibrated displacement volume inside the barrels. A photo electric detector consisting of a light source, fiber optics, and a photo conductor were used as the triggering mechanism. The light source was positioned in front of the flag and as the liquid level rose, the upper slot passed the photo conductor permitting light through. This provided the start signal for the instrumentation. The stop signal was initiated when the lower slot passed the photo conductor.

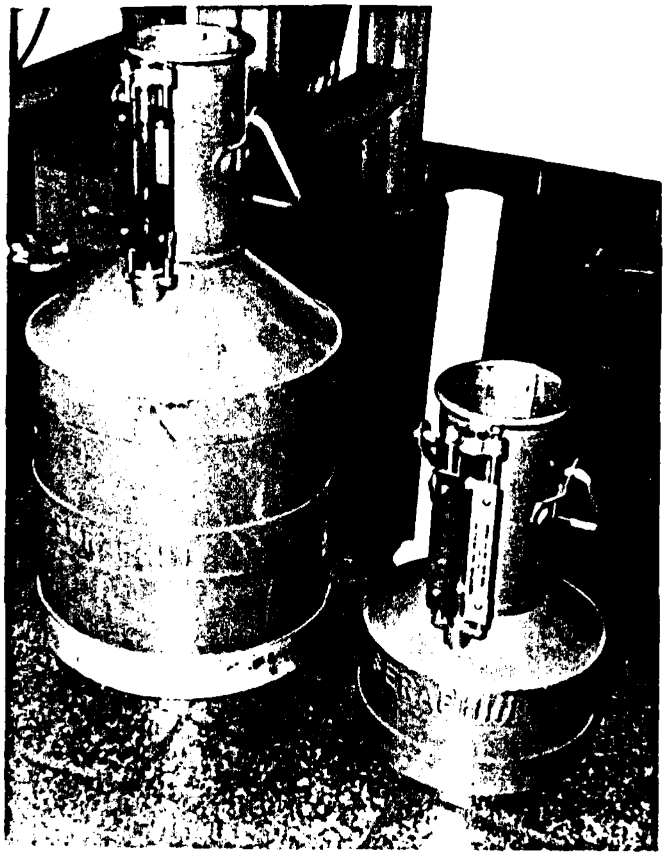


Figure 2.6.1

VOLUME STANDARDS

[illegible] test measures used to determine the displacement [illegible] within the volume calibrator are pictured above. The [illegible] test measures are at the right and left [illegible]

## 2.6 Flow Calibration

### 2.6.1 Introduction

Flow calibration on the working instruments was performed using a "time-volume" liquid flow calibrator. The method employed is called a standpipe, or level sensing method and the flow rate is determined by measuring the time required for the liquid surface to travel from one predetermined level to another.

#### 2.6.1.1 Definitions

1. Flow Rate - The volume of a fluid passing through a conductor per unit of time.

2. Flow Calibrator - Container with calibrated volume and a system which provides a start and stop signal to determine the interval of time required for the fluid to be displaced into the calibrated volume.

3. Displacement Volume - The calibrated volume of fluid to be displaced into the flow calibrator.

### 2.6.2 Traceability

Frequency - Frequency is traceable to NBS through ABC Television Network and NBS. Time and Frequency Bulletin No. 250 September 1978. Accuracy is certified to 3 parts in 1 million.

NOTE: Because of the relationship between time and frequency ($f = \frac{1}{\text{period (time)}}$) the error is assumed to be the same whether using time or frequency. See paragraph 2.5 (Frequency Calibration).

Volume - Volume is traceable to NBS through Seraphin 5 gallon and 1 gallon test measures, through the Wisconsin Dept. of Agriculture - Weights and Measures Laboratory. Wisconsin Test No. 816 dated February 2, 1978.

2.5.4 Results

NBS has to measure all these signals as they occur and publish the result after the fact. However the atomic clock drift is so little and the standard offset is very rarely violated except for component failures and down time which is published.

2.5.5 Conclusions

2.5.5.1 Uncertainty of Laboratory Reference Standard is $1.1 \times 10^{-3}$ hz.

2.5.5.2 Uncertainty of Working Instruments

| Counter No. | Uncertainty |
| --- | --- |
| 1985 | $1.1174 \times 10^{-6}$ sec |
| 3869 | $2.5142 \times 10^{-6}$ sec |
| 3870 | $8.3809 \times 10^{-7}$ sec |
| 3874 | $8.3809 \times 10^{-7}$ sec |

using the time zone you are in and the appropriate week in which the calibration was performed, read the offset listed in parts $10^{11}$.

2. This number should only vary from (-3000), which is the ideal number (this corresponds to exactly 3579545.4 Hz), by only $\pm$ 10 parts; i.e. (-3010) to (-2990) parts in $10^{11}$. This variation is so small that it only affects the 12th digit.
3. Correct the color subcarrier frequency at calibration time using the relative offset for the same time period and compare this number to the number recorded from the Frequency counter at calibration time, to determine calibration traceable to NBS.

10. To get time traceable to NBS, one merely has to take the inverse of the Frequency recorded at calibration time.

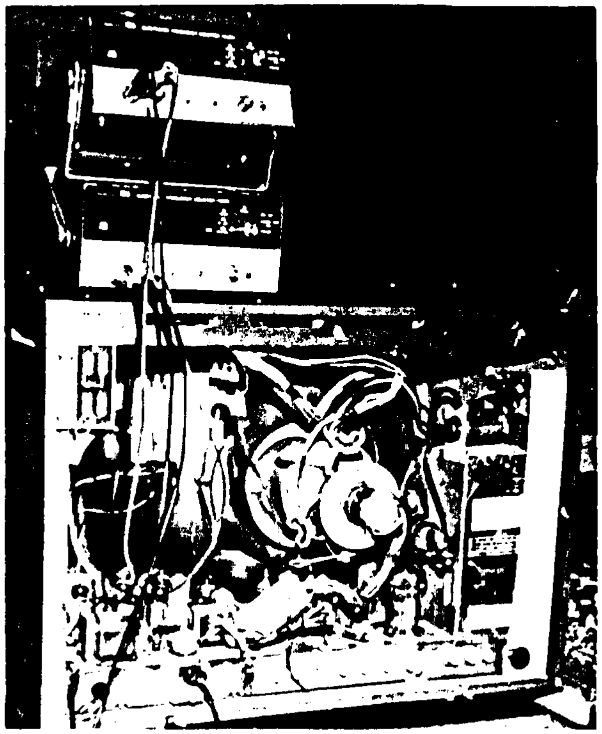


Figure 2.5.1

COUNTER CALIBRATION

Frequency counter calibration using the 3.58 MHZ frequency test point available from the color television set.

4. Warm up the frequency counter for at least an hour prior to calibration. This is very important because it allows proper stabilization of the internal clock.

5. Prior to calibration order the NBS monthly Time and Frequency Measurement Publication report for the next month. See Appendix B for address.

   This is an official publication of the National Bureau of Standards and is needed to verify the accuracy of the calibration on the day that it was performed. It contains a list of how far off from the center frequency the color subcarrier was for the particular day; and for the particular network used.

6. Tune the color television set to either an ABC, NBC or CBS network program, such as ABC Evening News, CBS Wednesday Night Movies, NBC Tonight Show etc.. Be sure to have a sharp picture (or a good, well defined waveform when viewing the color subcarrier on an oscilloscope).

7. Connect the set to the frequency counter to be calibrated, observing signal and ground connections. Adjust the input triggering level until a properly locked in signal is obtained. The counter should read 35795454 HZ + 1 count on the least significant digit.

8. Adjust the counter to read 35795454 (repeating) by tuning the crystal oscillator loading capacitor. This is the Fine Frequency Adjustment on the counter and is clearly accessible and labeled on most Frequency counters.

9. You can now assume the frequency counter to be tenatively calibrated and ready for us. It is very important to tag the frequency count with the following information because it will be needed at a later:

   A. Date calibrated
   B. Time calibrated
   C. Network used for calibration
   D. Programing at the time of calibration.

   This data will be needed to check the accuracy of the color subcarrier at the time of calibration in the following manner:

   A. See Appendix B page [illegible] of this report.
   B. The measurement periods listed are an actual sample page from the NBS Time and Frequency bulletin for August of [illegible].

A prescaler is an electronic counting device which divides high frequency by a factor, usually an integer power of two ($2^n$). A single device may provide division up to $2^{10}$ counts input per every count output.

The same calibration would be obtained with a crystal reference but to a lesser accuracy, up to one part in $10^7$ reliably which is traceable if the references are maintained calibrated to NBS at regular suggested intervals. This interval is dictated by the drift rate of the crystal reference, usually given in parts $10^9$ to parts in $10^{11}$ per day.

There is a way however, to obtain a useable reference signal whose frequency is from an NBS traceable cesium or rubidium source. This signal is the color frequency subcarrier for color television which is under strict NBS supervision and must be within a strict tolerance of plus or minus 4 x $10^{11}$ parts. However, this figure is based on an averaging of 150 hours per week and cannot always be expected to be this small. The deviations from 3.58 megahertz NBS color frequency for the three major networks are published monthly and are given in parts deviation in $10^{11}$. Note that the standard offset is minus 3000 parts in $10^{11}$. See the sample from the February 1979 issue of the NBS Time and Frequency Bulletin in appendix B. This publication is available from the Department of Commerce, NBS, free of charge. See appendix B for address.

The color frequency subcarrier is available from the output of the color demodulator circuit in any color television and one must refer to the schematic for the television in question for the proper pickoff point, usually clearly shown. However note that the program on the set must originate at the major network, in other words the program must be a network movie or news broadcast and not a local station program or show.

2.5.3.1 Procedure

1. Obtain any working color television receiver.

2. Record the make, model number and year of the television set and send this data to Sam's Photo Fact Company to obtain an electrical schematic diagram of the unit. See Appendix B for address.

3. Once the electrical schematic has been obtained, a qualified technician can find the output of the Chroma Demodulator circuit. This circuit locks on to the received color reference subcarrier signal and feeds it to the output of the circuit. A number 18 AWG lead should be soldered to this point and brought to the outside of the television set. This lead is then connected with the appropriate ground to the frequency counter to be calibrated.

would be a very good correlation between the pieces of equipment.

However if one needs the full accuracy of the atomic reference, up to plus or minus $3 \times 10^{11}$ parts there will be disagreement even in the atomic clocks. But a more common case is that most people (companies) cannot afford an atomic reference and usually have at best a stabilized crystal in their labs which will disagree at normal accuracy levels at one part in $10^7$ which would cause disagreement in most normal test equipment. This problem of non-correlation between test equipment and various lab calibration references seems very discouraging and even unsolvable.

However the federal government and industry saw the need for a solution to this problem, possibly a place which would contain a master reference (clock) from which all references could be calibrated and likewise all counters and timers would be calibrated from these secondary references. Both these secondary references and the equipment calibrated from them could be termed traceable to this master reference clock and therefore would all correlate within their inherent accuracies and all measurements made with traceable gear would also correlate.

As mentioned before the federal government saw this need with industry and started what is now known as the National Bureau of Standards, NBS for short. All equipment in the country which will make measurements needed by other companies for critical specifications should be officially termed "NBS traceable" and bear this label and be checked periodically. It now should be apparent that all support equipment (in our case time) should be traceable so the field service people in Ohio will measure the same flow rate at a certain rpm as the R & D technicians did at the factory in Wisconsin.

### 2.5.3 Calibration of Working Instrument

Now that the reasons for calibration traceability are understood along with what is being calibrated one may ask how traceable calibration is obtained?

One way as mentioned before is to have an atomic standard in the lab and adjust the counter to read the standards traceable output frequency. However most counters are accurate to only plus or minus one count and one must bear this in mind when adjusting the internal clock. The frequency of most references of this type would overrange most counters and therefore one must use a prescaler to divide the frequency down to a useful magnitute. Accuracies of up to one part in $10^{10}$ can be obtained on location in this manner.

Most of today's electronic counters in timers use a time base which employs an electro-mechanical crystal which by its physical geometry oscillates at a stable, fixed high frequency which is accurate enough for the resolution required by the device. The frequency is counted down by electronic means and this yields a very accurate interval clock for measurements. For now let's say the crystal oscillator has been factory calibrated for proper frequency, this will be explained. The crystal reference is used in most lab equipment and is low cost and relatively stable if kept at constant temperature, usually in an oven contained in the equipment. However, the frequency of the crystal will eventually drift out of calibration (age) and the measurements performed with the instrument after this occurred will be inaccurate.

However one may ask is there some sort of oscillator which doesn't drift significantly and is highly accurate? There is a type of oscillator reference which is extremely accurate but highly expensive. This device is the cesium clock or cesium oscillator which depends on a physical parameter of the cesium atom for its frequency of oscillation. Without getting into much detail, the alkaili metal cesium has two electronic spin states, which differ in energy by a quantized amount. In addition to the spin state of the electron in the outside shell of atom which precesses on its axis of travel on an eccentric path the frequency of precession is an extremely important and accurate physical constant of 9.192 x $10^9$ hertz. The difference between the spin state can be obtained (electron placed in a higher energy spin state) by exciting the vaporized cesium with the same frequency r.f. energy as its resonance (9.12 x $10^9$ hz). This higher energy state can be sensed by a great increase in electric conduction of the vapor placed in an electric field. By using feedback one can devise a circuit which adjusts its own oscillator to match the resonant line of the cesium. This frequency is accurate to within one part in $10^9$ and can be stabilized to within three parts in $10^{11}$. This frequency can be beat down to a useable reference for calibrating crystal based equipment to maximum attainable accuracy of the equipment. These cesium devices are now made small enough to fit in a standard 19 inch relay rack but are extremely expensive initially and hard to maintain. It will be shown later that a cesium grade reference signal can be obtained without owning your own reference clock at low cost. As a final word there are also references based on other elements such as rubidium.

### 2.5.2 Traceability

The atomic reference is very accurate but even it has limits in its inherent accuracy. If everyone had an atomic reference and used to calibrate this normal grade equipment there

## 2.5 Frequency and Time Calibration

### 2.5.1 Introduction

Whenever a quantity is measured in the laboratory or field which involves time in some respect as a fundamental unit, one relys on the fact that an interval of time through which the measure is made is absolute plus or minus some uncertainty. However, of what value is a time measurement made with an uncalibrated instrument? The data taken under this stipulation is virtually worthless for two basic reasons:

1. The data can never be repeated reliably in other locations with other pieces of test gear because there will be no correleation between them.

2. The component data which is main criterion for selecting parts in a design will be useless and could have inaccuracies misleading the designer into selecting the wrong components which may lead to catastrophic failures.

The only way to avoid this problem is to have equipment which is in calibration with respect to two criterions.

1. To have equipment in absolute calibration according to the physical definition of the quantity measured.

2. To be in calibration identical to the calibration of other pieces of equipment which also measure the same physical quantity.

In other words the goal is to obtain a piece of test gear which accurately measures absolute time intervals and has good data correlation with other instruments that also measure time. This correlation is extremely important and has its roots in a term referred to as traceability and will be treated more thoroughly later after some needed ground work is laid.

Considering fluid power measurement as a special case one finds a high reliance on time as a base unit. In other words many fundamental quantities in fluid power use time such as flow rates, rpm, velocities, etc.

In actuality the measurement of time and frequency are very similar in nature. To measure the time interval one starts a timing device with the beginning of an event and stops the device at the end of the event, this gives elapsed time. However with frequency measurement one counts a number of occurrences in a set time interval to yield events per second or cycles per second depending on which is more meaningful. However both of these time related tests require a time reference of suitable accuracy and stability for the resolution and accuracy demanded by the application.

### 2.4.4 Results

The data obtained from the calibration procedure was used to derive a Third Order Mathematical Model of the working instrument as described in appendix G, annex C, section 7. The model was then entered into a computer file and corrections were applied to the test data prior to further processing in the computer.

### 2.4.5 Conclusion

The calibration results of the working instrument are shown in appendix A for each transducer calibrated.

2.4.5.1 Uncertainty of Laboratory Reference is 10 psi when using the large diameter piston and .25 psi when using the small diameter piston.

2.4.5.2 Uncertainty of Working Instruments

| Transducer No. | Uncertainty | |
|---|---|---|
| 327876 | 15.5 psi | Calibrated With Large Diameter Piston |
| 327976 | 13.2 psi | |
| 328076 | 14.3 psi | |
| 328176 | 13.1 psi | |
| 12752 + port pressurized | .268 psi | Calibrated With Small Diameter Piston |
| 12752 - port pressurized | .253 psi | |

(water level in the volume calibrator rose) until the circuit triggered. The needle valve was quickly shut off and the water level in the plastic tube was marked. The liquid level in the plastic tube was raised and lowered nine more times, each time marking the level at which the circuit triggered.

Another arbitrary datum was selected on the plastic tube and the distance from this datum to each of the ten recorded levels was measured and an average was calculated. This was designated as the best estimate of the lower displacement volume level. (Standard deviation of the lower level trigger points was 1.1 cu in. out of 9333 cu in.). The formula used to determine the displacement volume was:

$$[illegible]\ \text{gal.})\left(231\ \frac{in^3}{gal}\right) - (2000\ cm^3)\left(.06102\ \frac{in^3}{cm^3}\right) - y\,\frac{D^2}{4}$$

Where: $\Delta y$ = the distance between the best estimate of upper and lower displacement volume levels as marked on the plastic tube.

D = the inside diameter of the plastic tube.

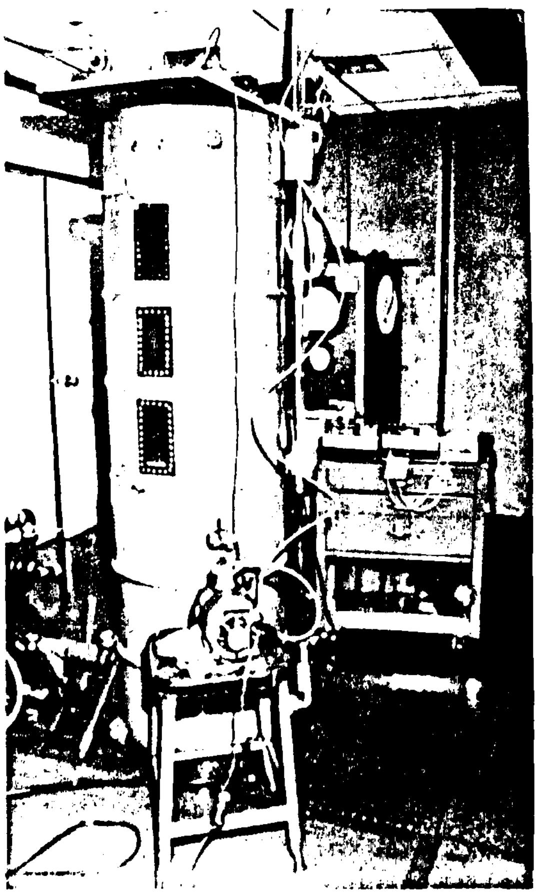


Figure 2.6.5

FLOW RATE CALIBRATION BARREL SETUP

Volume calibrator with the plastic tube attached to the side. On top is the electronics which sensed the passage of the slots and provided the start and stop signal for frequency counters. The vacuum pump (on stool) was used to draw water up the plastic tube.

### 2.6.4 Calibration of Working Instrument

2.6.4.1 Description of working instrument - Two working instruments were calibrated. A 10 $in^3$/rev and a 2.3 $in^3$/rev, positive displacement, balanced vane type, commercial grade hydraulic motors were used as flowmeters. The 10 $in^3$/rev flowmeter has an 80 tooth gear on the output shaft. A magnetic sensor with the appropriate electronic conditioning equipment was mounted near the gear teeth to monitor the passage of each tooth. The frequency counter records the passage of one tooth as one pulse. The 2.3 $in^3$/rev flowmeter is identical to the 10 $in^3$/rev with the exception of the number of teeth on the output shaft. The 2.3 $in^3$/rev flowmeter has a 120 tooth gear on its output shaft.

2.6.4.2 Procedure for Working Instrument Calibration The 10 $in^3$/rev flowmeter and the volume calibrator were plumbed in series to the outlet of FPI's 150 HP Hydraulic Supply. An essentially constant flowrate was established through the flowmeter and into the volume calibrator. At the instant the liquid boundary reached its lower displacement volume level, the upper slot on the flag passed the stationary light source and provides a simultaneous start signal to 2 frequency counters. One frequency counter was set up for the totalize elapsed time function and the other was set up for total counts - i.e. the total number of gear teeth from the output shaft of the flowmeter passing the magnetic sensor was summed over the duration of each run. When the liquid boundary reached the upper displacement volume level, the lower slot on the flag passed the light source and provided a simultaneous stop signal to both counters. Six trials at eight incremental flowrates were performed for a total of 48 data points. The incremental value for flowrate was 5 GPM, and ranged from 5 to 40 GPM.

This same procedure was repeated for the 2.3 $in^3$/rev flowmeter with the exception of the number of trials. Five trials at eight incremental flowrates were performed for a total of 40 data points. The incremental value and range of the flowrate was identical to the 10 $in^3$/rev flowmeters. Six trial runs were performed on the 10 $in^3$/rev flowmeter and five trial runs were performed on the 2.3 $in^3$/rev flowmeter.

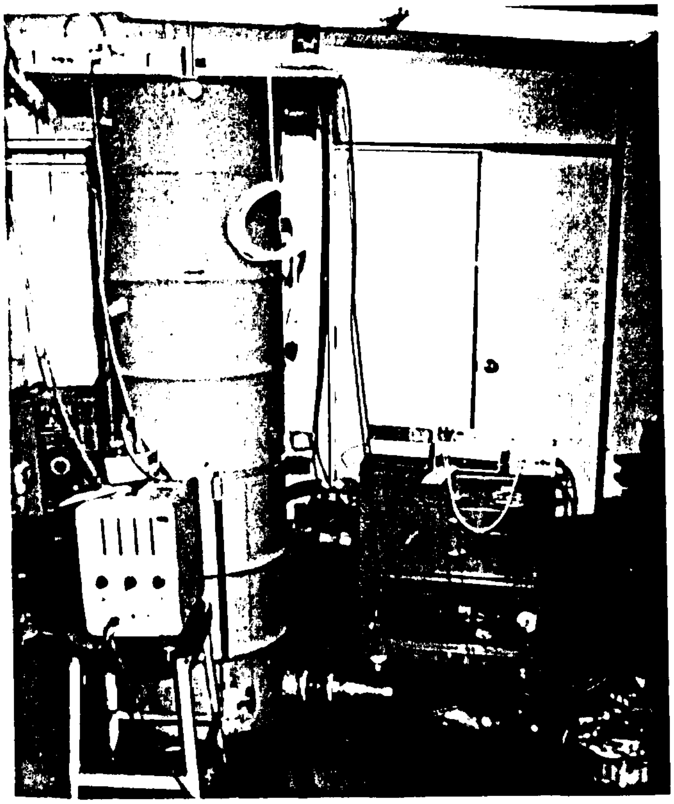


Figure 2.6.6

FLOWMETER CALIBRATION CIRCUIT

The [illegible] cu in/rev, PD flow meter (far right) was plumbed in series with the supply pump and flow rate calibrator. As the liquid level rose, the upper slot passed the light source and started the counters. When the lower slot passed the light source, the counters stopped.

2.6.5 Results - Per Appendix G, Annex C

2.6.5.1 Math Model of Laboratory Reference - A third order math model with only one calibration trial was used to determine the value of calibration error on the flow rate calibrator.

2.6.5.2 Math Model of Working Instrument - A third order math model (point to point correction) was used to determine the value of calibration error on the 10 $in^3$/rev and 2.3 $in^3$/rev flowmeters. Six trial runs were performed on the 10 $in^3$/rev flowmeter and five trial runs were performed on the 2.3 $in^3$/rev. flowmeter.

2.6.5.3 Flowmeter Data Reduction - Because of the inability to return to an exact flowrate on subsequent trial runs at each target flowrate the following method of data reduction was adopted:

1. Measure time (sec.), Volume (constant gallons), Total Counts (pulses).

2. Calculate frequency for each of five trial runs at each target flowrate $\frac{\text{total counts}}{\text{time}} = f_o$.

3. Calculate flowrate for each of five trial runs at each target flowrate $\frac{\text{Volume}}{\text{time}} = Q_o$.

4. Calculate ratio for each of five trial runs at each target flowrate $\frac{\text{frequency}}{\text{flowrate}} = \frac{f_o}{Q_o}$.

5. Designate the calculated flowrate from the first of five trial runs at each target flowrate as the Reference flowrate $Q_{Ref}$.

6. Multiply the ratio of $\frac{f_o}{Q_o}$ by the reference flowrate $Q_{Ref}$.

   to obtain a theoretical frequency $f_\theta$ at each of five runs for each target flowrate.

7. Calculate the average theoretical frequency from the five obtained in step #6 at each target flowrate $f_\theta$ ave.

8. Subtract the average theoretical frequency from each of the five theoretical frequencies obtained in step #6 at each target flowrate.

9. Twice the standard deviation of all the deviations from the averages was designated as the calibration error.

This procedure enables the theoretical frequencies to be plotted versus one value of flowrate. See Figure 2.6.7. The non-linearity is exaggerated for explanitory purposes.

### 2.6.6 Conclusions

#### 2.6.6.1 Uncertainty of Laboratory Reference.

| | | |
|---|---|---|
| 1. | Uncertainty from NBS | 2.079 cu.in. |
| 2. | Uncertainty from Wisconsin Dept. of Agriculture | 2.16 cu.in. |
| 3. | Uncertainty from FPI Technician (est.) | 4.5 cu.in. |
| 4. | Uncertainty of Seraphin bucket readability | 4.05 cu.in. |
| 5. | Uncertainty from switch repeatability (Composite of upper and lower) | 3.905 cu.in. |
| 6. | Uncertainty due to thermal expansion | 1.8 cu.in. |
| 7. | Uncertainty due to clingage | 8.0 cu.in. |
| | | 26.49 cu.in. |

$$\text{Total Uncertainty} = \frac{26.49}{9333.22} \times 100 = 0.286\%$$

#### 2.6.6.2 Uncertainty of Working Instrument.

A. 10 cu. in. PD Flowmeter
Error = $\pm$ (.047 gpm + 0.286% of Q)

B. 2.3 cu. in. PD Flowmeter
Error = $\pm$ (.0165 gpm + 0.286% of Q)

All flowmeter calibration data is contained in appendix C. Repeatability was found to be $\pm$ .047 and $\pm$ .0165 gallons per minute for the 10 $in^3$ and 2.3 $in^3$, respectively. The total uncertainty in the volume calibrator (26.49 $in^3$ out of 9333 $in^3$) passes through to the flowmeter as a % of reading error. Results of the repeatability tests indicate that any future efforts to reduce the systematic error in the volume calibrator would be justified.

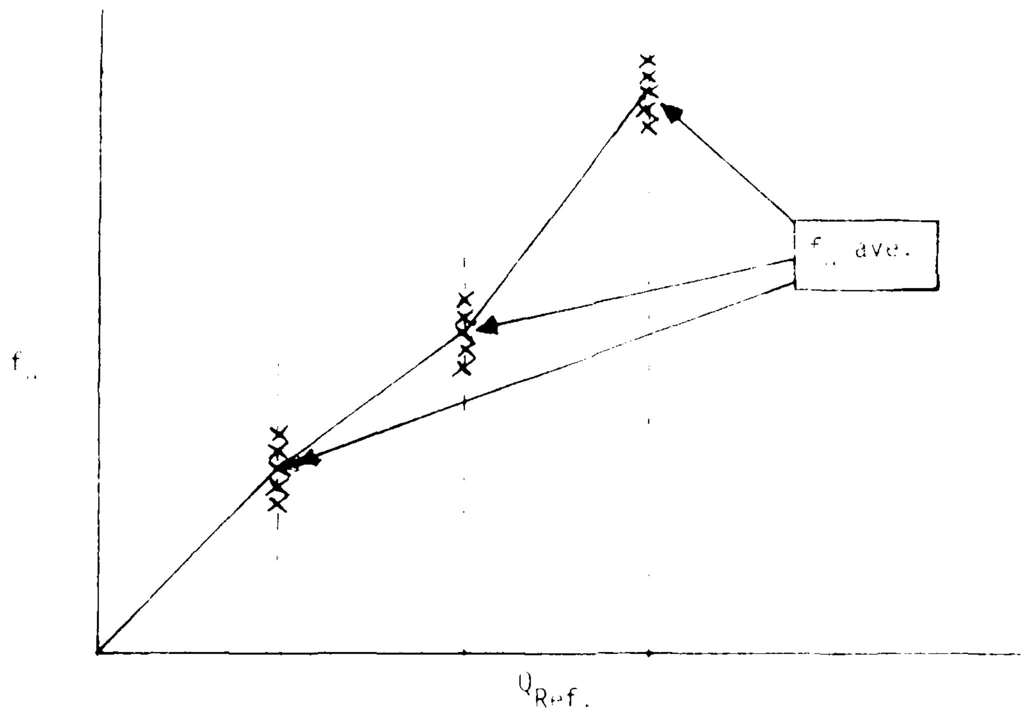



Figure 2.6.7

THEORETICAL FREQUENCY VS. FLOW RATE

## 2.7 Load Cell and Torque Shaft Calibration:

### 2.7.1 Introduction

Torque calibration of the working instrument was performed by using air cylinders to apply a force at a known distance from the central axis of the working instrument.

The working instrument was vertically mounted, with the force being applied horizontally in a direct couple. There were two main reasons for using this method. The first was to reduce the possibility of error due to side loads. The second was to eliminate the need for the technician to load and remove weights. At low torque values, such as 2000 inch-pounds, these benefits were minimal, however, with larger torques, such as 500,000 inch-pounds, the amount of weight and resulting side loads could be substantial.

When this method was originally conceived, the plan was to calibrate a pair of rolling diaphram air cylinders. Unfortunately, the output force varied as a function of position as well as air pressure. Although this tendency was relatively slight, the accuracy and repeatability required of the force in this calibration procedure could not be attained. The decision was then made to purchase load cells, which were mounted on the end of the cylinder rods. A diagram of torque calibration rig is shown in Figure 2.7.2.

#### 2.7.1.1 Definitions

1. Couple: Two forces having the same magnitude, parallel lines of action, and opposing direction.

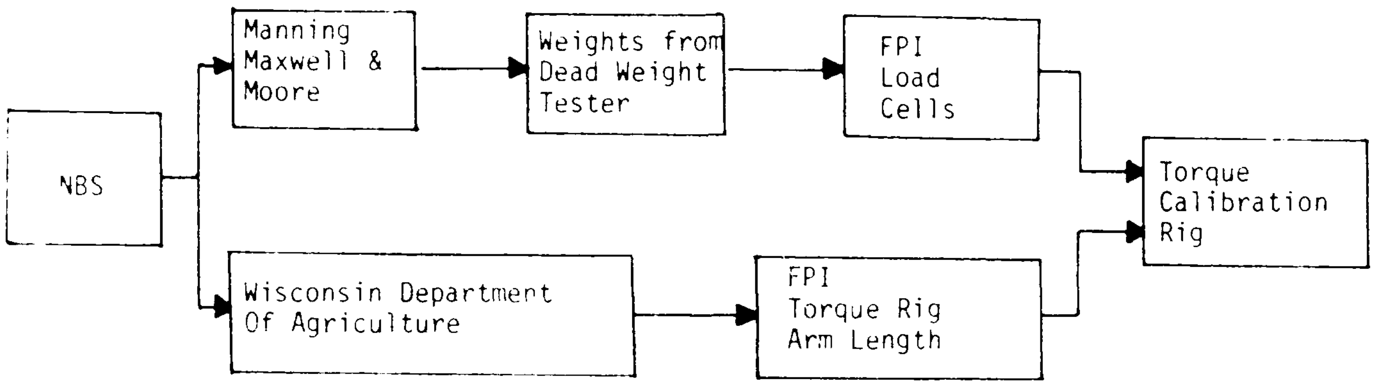
2. Moment: The product, of the magnitude of a force, and of the perpendicular distance from axis to the line of action of the force.

3. Torque: A moment in the form of a couple causing torsional loading.

### 2.7.2 Traceability

Force - Force is traceable to NBS through the weights of the Ashcroft dead weight tester, as described in section 2.4.2.

Distance - Distance is traceable to NBS through the Wisconsin Department of Agriculture - Weights and Measures Laboratory. Wisconsin Test Number 868, Dated September 7, 1978.




TRACEABILITY FLOW CHART

Figure 2.7.1

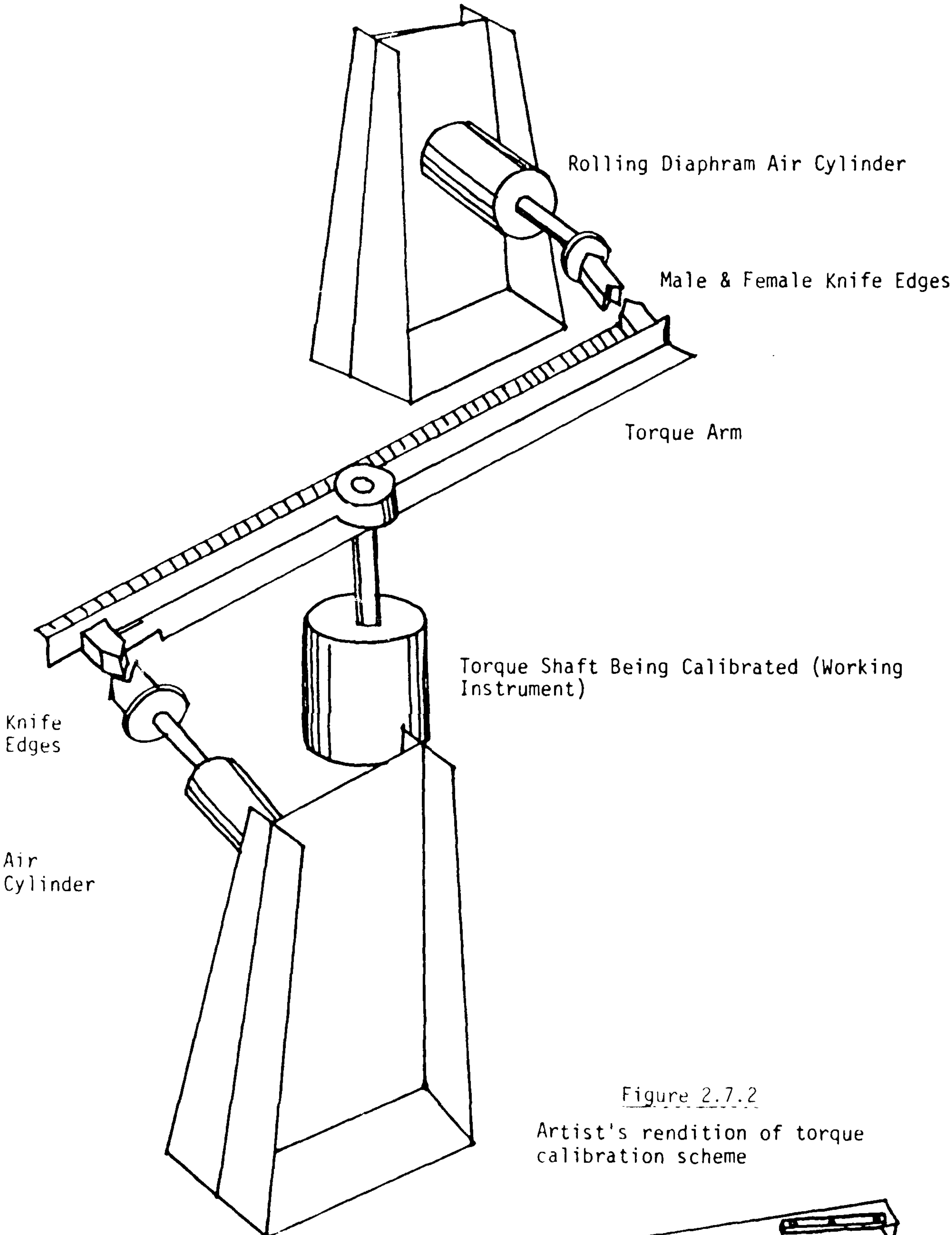



Figure 2.7.2

Artist's rendition of torque calibration scheme

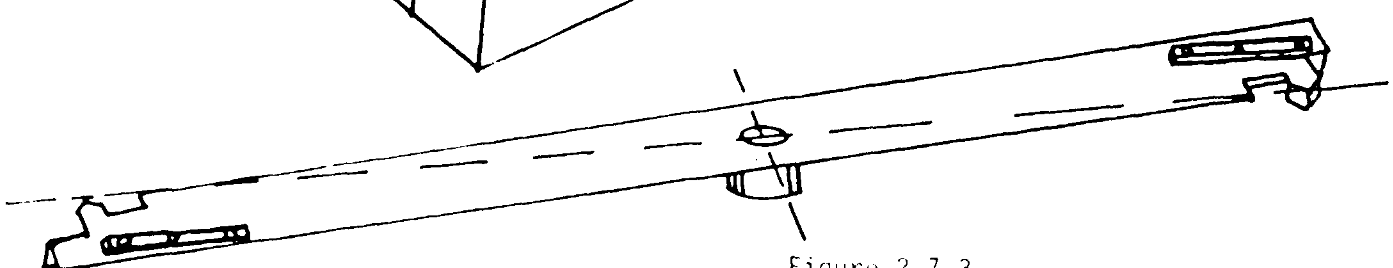


Figure 2.7.3
Torque Arm

### 2.7.3 Description of the Torque Calibration Rig

The laboratory standard, (torque calibration rig) as shown in figure 2.7.2 consisted of a machined surface on which the torque shaft transducer was vertically mounted. Also attached to the surface were two (2) support brackets, which held the air cylinder and load cell assemblies. The torque arm, as shown in figure 2.7.3, is a "T" shaped beam with male knife edge bearings at the opposing ends. Permanently attached at each end of the torque arm is an alignment fixture, consisting of a section of 5/16" keystock mounted parallel to a line intersecting the tips of the male knife edges. The force was applied perpendicularly to the torque arm using the alignment fixtures as a reference. The force was measured by the load cells mounted between the air cylinders and the female knife edges.

#### 2.7.3.1 Procedure for Calibration of the Load Cells

Each load cell was electrically connected to one channel of a two channel Daytronic Model 300D transducer power supply/amplifier. A Fluke vacuum tube voltmeter was used as the readout device. Prior to calibration the zero was set and the gain was adjusted using the calibration resistor and output valve supplied by the manufacturer.

The load cells were calibrated using weights from the Ashcroft Dead Weight Tester as described in section 2.4. Each weight was certified at 2835.0 + 1.4 grams, or 6.251 $\pm$ .003 pounds.

12 weights were used to achieve the maximum value. The procedure consisted of mounting the weight pan, recording the output voltage, then adding a weight and tapping on the weight to reduce hysteresis.

This method was used for increasing and decreasing increments. The procedure was repeated for a total of 5 trials.

#### 2.7.3.2 Estimated Uncertainty of the Load Cell Output

There are three contributors to the total uncertainty in load cell output:

1. Readability error of the readout device.

2. Reference standard error.

3. Calibration error.

The readout device was a John Fluke differential voltmeter with a readability error of 0.5 millivolt out of a full scale value of about 7500 millivolts. This produces a readability error of 0.005 lb.

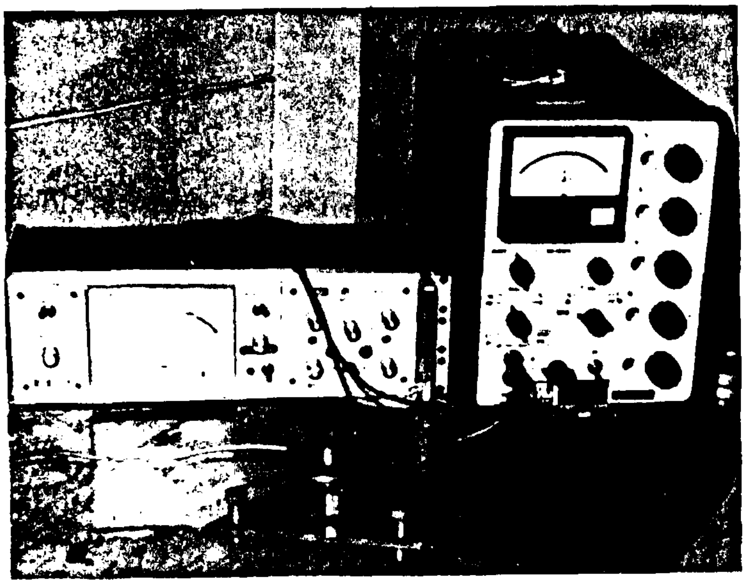


Figure 2.7.4

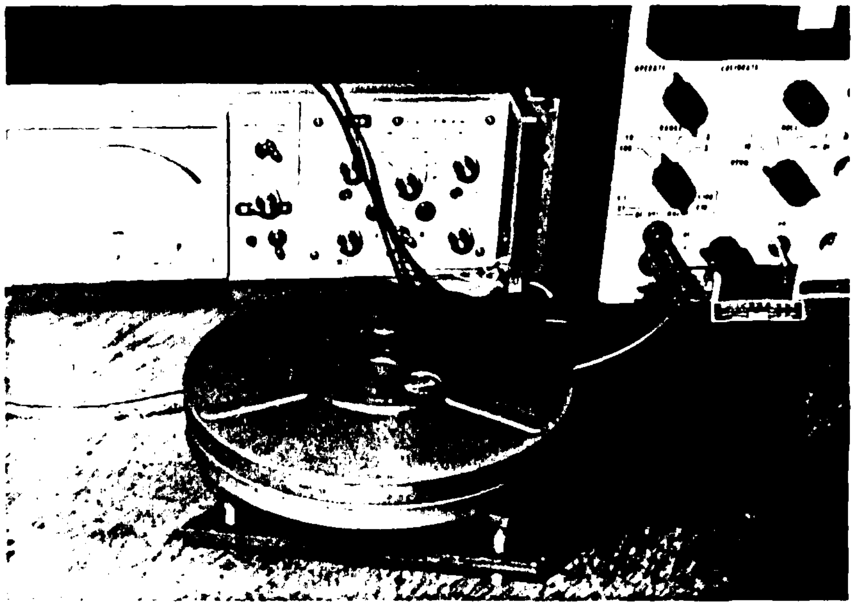
LOAD CELL INSTRUMENTATION

Lebow load cell, calibration fixture, weight pan, Daytronics amplifier and Fluke VTVM used as the readout device.

Figure 2.7.[illegible]

LOAD CELL CALIBRATION

Lebow load [illegible] being calibrated [illegible] the [illegible] weight [illegible]



The reference standard error, that is, the error of the calibration dead weights is given by Manning, Maxwell and Moore as being 0.05%, which resolves into 0.0375 lb.

Analysis of calibration data for all five increasing and decreasing trials shows that the $2\sigma$ deviation about the third-order model is about 0.08 lb.

The total uncertainty in one of the load cells is the sum of the three terms:

Total Error in lb = 0.005 + 0.0375 + 0.08 = 0.122 lb.

In percent, $\frac{0.122 \times 100}{75.375} = 0.162\%$

Both load cells yielded almost identical results, so much so that any differences were insignificant.

### 2.7.4 Description of the Working Instrument

The working instrument was a Himmelstein non-contacting rotary transformer torque transducer with a 2000 inch-pound shaft installed. Torque sensing is accomplished with a four-active-arm strain gage bridge.

#### 2.7.4.1 Procedure for Working Instrument Calibration

The torque transducer was mounted on the torque calibration rig and electrically connected to a Daytronics Model 3278 digital amplifier/power supply.

Prior to calibration the transducer zero was set and the gain was adjusted to obtain an adequate span.

To establish perpendicular lines of force, a drafting triangle was attached to the torque arm and flush mounted with the alignment fixture. The support bracket air cylinder assembly was positioned so the air cylinder rod was parallel to the 90° edge of the drafting triangle.

The calibration procedure consisted of increasing the force applied by the air cylinders, while tapping on the torque calibration rig, until the first of ten evenly incremented target values was achieved on the output of the torque transducer. The purpose of tapping on the torque calibration rig was to overcome the break-away friction of the air cylinders and the torsional friction in the knife-edge bearings. The target values were read from the output of the torque transducer amplifier, because there were two inputs neither of which were repeatable, and only one output which was very repeatable.

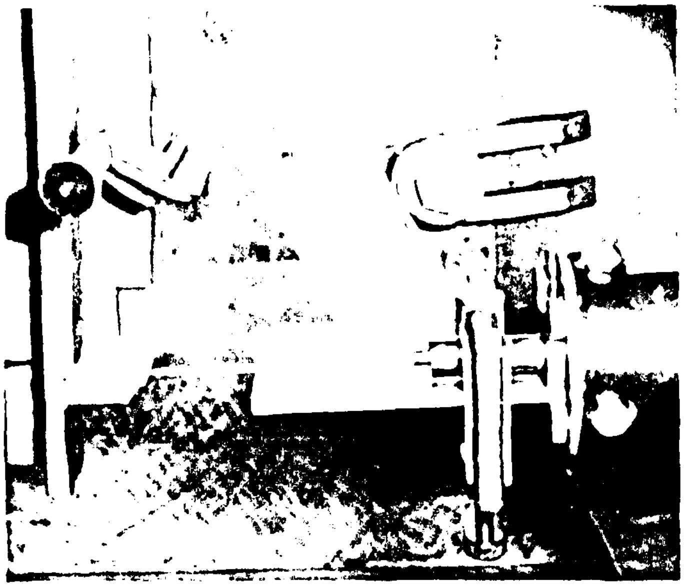
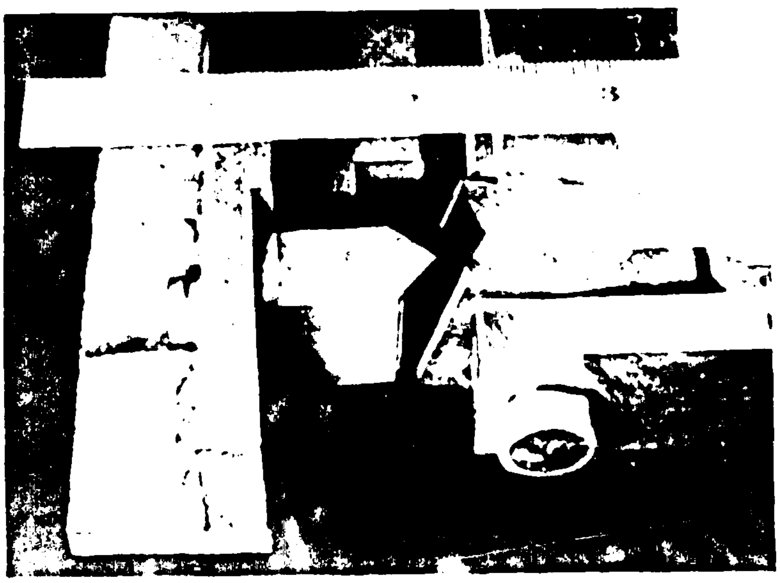


Figure 2.7.6

AIR CYLINDER POSITIONING

Drafting triangle mounted on load beam against alignment fixture to position the air cylinder rod at a 90° angle to the male knife edge on the load beam.

[illegible]



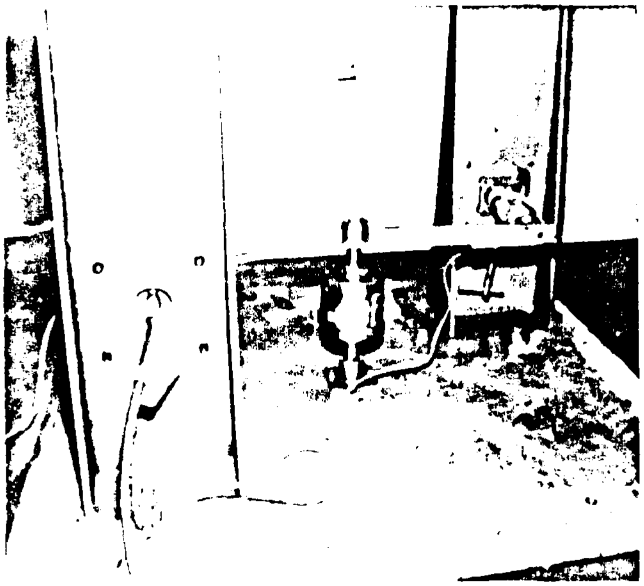


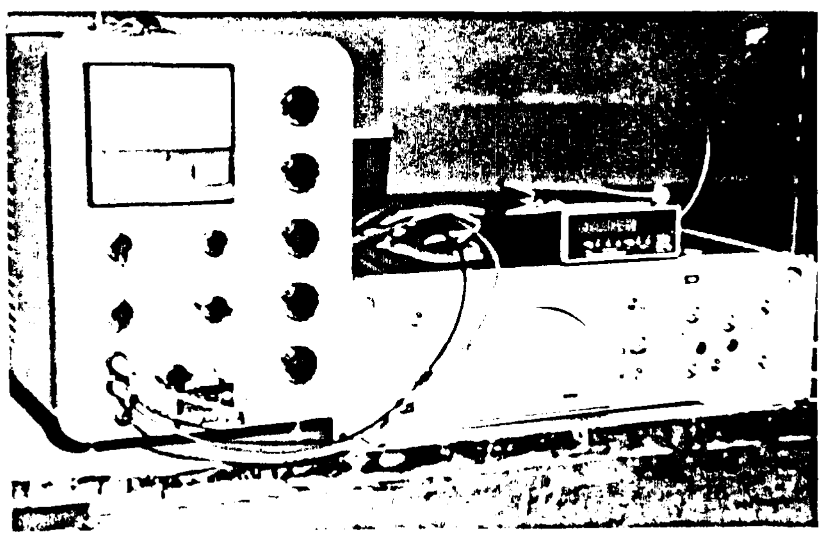
Figure [illegible]

TORQUE SHAFT CALIBRATION

Torque shaft installed in calibration fixture with load beam and vertical supports for mounting the air cylinders and load cells. Equal forces were applied to both ends of the load beam to eliminate side loading and bending.

[illegible]ATION

[illegible]



PROJECT NO. 50560

DATE 4/23/78

TECHNICIAN D. Gerber

INSTRUMENTATION

Reference Standard = 25 psi

Calibration Error ±.0172psi

Readability error ±.001 psi

Error ±.2682psi

Trial #3

| | Zero Volts | Increas. Volts | Decreas. Volts |
|---|---|---|---|
| [illegible] | 0.001 | 0.503 | 0.503 |
| [illegible] | 0.004 | 0.896 | 0.891 |
| [illegible] | 0.000 | 1.480 | 1.482 |
| [illegible] | 0.000 | 2.001 | 2.003 |
| [illegible] | 0.009 | 2.473 | 2.473 |
| [illegible] | 0.010 | 2.987 | 2.989 |
| [illegible] | 0.002 | 3.544 | 3.560 |
| [illegible] | 0.008 | 3.996 | 4.004 |
| [illegible] | 0.011 | 4.499 | 4.512 |
| [illegible] | 0.000 | 4.996 | 4.997 |

4/23/79

D. Gerber

Error of Reference Standard = .25psi

Calibration Error =.0015psi

Readability Error = .001psi

Total Error =.2525psi

Trial #3

| Decrease Volts | Zero Volts | Increase Volts | Decrease Volts |
|---|---|---|---|
| 0.45[illegible] | 0.000 | 0.450 | 0.452 |
| 0.964 | 0.008 | 0.975 | 0.976 |
| 1.498 | 0.000 | 1.495 | 1.496 |
| 1.998 | 0.002 | 1.995 | 1.998 |
| 2.502 | 0.002 | 2.502 | 2.506 |
| [illegible] | 0.003 | 3.010 | 3.013 |
| 3.529 | 0.005 | 3.525 | 3.529 |
| 4.015 | 0.017 | 4.011 | 4.015 |
| [illegible] | 0.000 | 4.518 | 4.524 |
| 5.025 | 0.008 | 5.019 | 5.024 |

| Decrease Volts |
|---|
| 0.4[illegible] |
| 0.97[illegible] |
| [illegible] |
| 2.00[illegible] |

FLUID POWER INSTITUTE
[illegible] SCHOOL OF ENGINEERING

TEST: [illegible] Pressure Transducer Calibration

PROJECT NO. 50560

DATE 10/10/78

TECHNICIAN R. D. G.
J. O. M.

DESCRIPTION: [illegible] 5000 PSI Pressure Transducer
Model #[illegible]-15 1 volt/1000 PSI
Serial #[illegible]

COMMENTS: Ashcroft Dead Weight Tester as a pressure standard
DAS for readout on channel #3
[illegible] Button Valve

INSTRUMENTATION
Error of Reference Standard ± 10 psi
Calibration Error ± 2.1 psi
Readability Error ± 1.0 psi
Total Error ± 13.1 psi

| Ashcroft Actual PSI | Zero Volts | Trial #1 Increas. Volts | Decreas. Volts | Zero Volts | Trial #2 Increas. Volts | Decreas. Volts | Zero Volts | Trial #3 Increas. Volts | Decreas. Volts |
|---|---|---|---|---|---|---|---|---|---|
| 500 | [illegible] | 0.501 | 0.501 | 0.000 | 0.502 | 0.502 | 0.000 | 0.503 | 0.501 |
| 1000 | [illegible] | 1.002 | 1.002 | 0.000 | 1.003 | 1.001 | 0.000 | 1.002 | 1.002 |
| [illegible] | 0.000 | 1.503 | 1.503 | 0.000 | 1.503 | 1.503 | 0.000 | 1.503 | 1.502 |
| [illegible] | 0.000 | 2.003 | 2.003 | 0.000 | 2.004 | 2.003 | 0.000 | 2.003 | 2.003 |
| [illegible] | 0.000 | 2.503 | 2.503 | 0.000 | 2.502 | 2.503 | 0.000 | 2.502 | 2.502 |
| [illegible] | [illegible] | 3.002 | 3.004 | 0.000 | 3.001 | 3.004 | 0.000 | 3.001 | 3.004 |
| [illegible] | [illegible] | 3.501 | 3.503 | 0.000 | 3.502 | 3.503 | 0.000 | 3.503 | 3.504 |
| [illegible] | [illegible] | 4.001 | 4.004 | 0.000 | 4.000 | 4.003 | 0.000 | 4.002 | 4.005 |
| [illegible] | [illegible] | 4.502 | 4.504 | -0.001 | 4.502 | 4.503 | 0.000 | 4.503 | 4.505 |
| [illegible] | [illegible] | 5.000 | | 0.000 | 5.005 | | 0.000 | 5.003 | |

| Ashcroft Actual PSI | Zero Volts | Trial #4 Increas. Volts | Decreas. Volts | Zero Volts | Trial #5 Increas. Volts | Decreas. Volts |
|---|---|---|---|---|---|---|
| [illegible] | [illegible] | 0.502 | 0.503 | 0.000 | 0.502 | 0.501 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1.003 | 1.003 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1.504 | 1.502 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 2.002 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 2.503 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 3.004 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 3.502 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 4.004 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 4.502 |

| | |
|---|---|
| | [illegible] |
| DESCRIPTION | [illegible] Transducer |
| | [illegible] PSI |
| REMARKS | [illegible] Standard |

| | |
|---|---|
| INSTRUMENT [illegible] | |
| [illegible] Reference [illegible] Standard | [illegible] psi |
| [illegible] Error | 2.3psi |
| Readability Error | 0psi |
| Total Error | 14.3psi |

| | | | | | | [illegible] #1 | | Valve #3 | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Increase | Decreas | Zero | | Decreas |
| | | | | | | Volts | Volts | | Volts |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | .502 | [illegible] | [illegible] | .502 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1.002 | [illegible] | [illegible] | 1.002 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 2.006 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 2.505 | 2.505 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 3.006 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 3.506 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 4.006 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | Volts |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

PROJECT NO. 5056[illegible]

DATE 10/10/78

TECHNICIAN R. D. G.

J. O. M.

INSTRUMENTATION

[illegible] Reference ± 10 psi

Standard [illegible] Error ±2.2 psi

[illegible]ty Error ±1.0 psi

[illegible] Error ±13.2 psi

Trial #3

| Volts | Zero Volts | Increas. Volts | Decreas. Volts |
|---|---|---|---|
| 0.503 | 0.000 | 0.505 | 0.505 |
| 1.005 | 0.000 | 1.005 | 1.005 |
| 1.506 | 0.000 | 1.506 | 1.505 |
| [illegible].006 | 0.000 | 2.005 | 2.006 |
| [illegible].505 | 0.000 | 2.505 | 2.505 |
| [illegible] | [illegible] | 3.005 | 3.006 |
| [illegible] | [illegible].000 | 3.504 | 3.505 |
| [illegible] | [illegible] | 4.005 | 4.006 |
| [illegible] | [illegible] | 4.507 | 4.506 |
| | | [illegible].007 | |

Volts

[illegible].506

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST [illegible] Pressure Transducer Calibration

DESCRIPTION [illegible] Pressure Transducer 0-5000 PSI
Model #218-15 1 Volt/1000 PSI
Serial #327876

COMMENTS Ashcroft Dead Weight Tester as a pressure standard
[illegible] for readout on channel #2
Cal. button Value

PROJECT NO. 50560
DATE 10/10/78
TECHNICIAN R. D. G.
J. O. M.

INSTRUMENTATION
Error of Reference Standard = 10 psi
Calibration Error =4.5 psi
Readability Error =1.0 psi
Total Error =15.5psi

| | Trial #1 | | | Trial #2 | | | Trial #3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Ashcroft Input PSI | Zero Volts | Increas. Volts | Decreas. Volts | Zero Volts | Increas. Volts | Decreas. Volts | Zero Volts | Increas. Volts | Decreas. Volts |
| [illegible] | - [illegible] | 0.499 | 0.499 | [illegible] | 0.503 | 0.503 | - 0.000 | 0.502 | 0.501 |
| [illegible] | [illegible] | 1.003 | 1.002 | 0.000 | 1.006 | 1.001 | - 0.002 | 1.000 | 1.001 |
| 1500 | - 0.001 | 1.50[illegible] | 1.50[illegible] | 0.000 | 1.509 | 1.506 | 0.001 | 1.503 | 1.506 |
| [illegible] | - [illegible] | 2.[illegible] | 2.0[illegible] | [illegible] | 2.008 | 2.009 | 0.002 | 2.009 | 2.006 |
| 2500 | [illegible] | 2.507 | [illegible] | [illegible] | [illegible] | 2.505 | - 0.001 | 2.503 | 2.506 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 3.0[illegible] | - 0.001 | 3.005 | 3.008 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 3.504 | 3.51[illegible] | - 0.003 | 3.505 | 3.507 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 4.003 | - 0.001 | 4.003 | 4.009 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 4.502 | - [illegible] | 4.50[illegible] | 4.503 |
| [illegible] | [illegible] | [illegible] | | | [illegible] | | | | |

| | Trial #4 | | | Trial #5 | | |
|---|---|---|---|---|---|---|
| Ashcroft Input PSI | Zero Volts | Increas. Volts | Decreas. Volts | Zero Volts | Increas. Volts | Decreas. Volts |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

# APPENDIX A

## PRESSURE CALIBRATION DATA

Ice was added to the water to get the water bath temperature below the first desired reading. The water bath was heated by a hot plate. Readings were taken every 10°F as indicated on the glass thermometer from 40°F to 210°F by the DAS printer. This procedure was repeated four more times to get five calibration trials of increasing values only.

The calibration procedure used follows the procedure described in appendix G, annex B.

The values of the reference thermometer were corrected using calibration data from the State of Wisconsin Bureau of Weights and Measures. This was done to obtain the true standard value for these temperatures.

2.8.4 Results

The data obtained from the calibration procedure was used to derive a third Order Mathematical Model of the working instruments as described in appendix G, annex C, section 7.0. The model was then entered into the computer to interpret the temperature readings from the test and corrected the data.

2.8.5 Conclusion

Several thermocouples were calibrated and the results for each are contained in appendix E.

2.8.6.1 Uncertainty of Laboratory Reference is 2.05°F.

2.8.6.2 Uncertainty of Working Instruments:

Thermocouple #0    3.88°F

Thermocouple #1    4.00°F

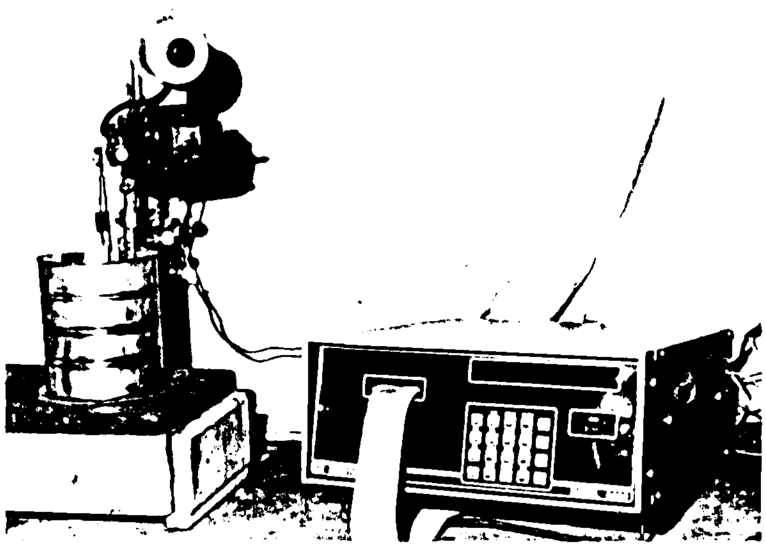


Figure 2.8.3

THERMOCOUPLE CALIBRATION

The mercury thermometer, thermocouples and stirring motor were mounted on a ring stand and placed in a container of water located on top of a hot plate. The data acquisition system was used to record the thermocouple output directly in degrees Fahrenheit.

Dissimilar metal thermocouples work on the principle of Electromotive Force (EMF) which is developed between the measuring junction and the reference junction whenever there is a temperature difference between the two. When the reference junction is kept constant at a known temperature the difference between the measuring junction and the reference junction is your unknown temperature which is measured and recorded by the Data Acquisition System.

### 2.8.2 Traceability

Our laboratory reference standard thermometer #673650 was calibrated by the Wisconsin Department of Agriculture, Bureau of Weights and Measures using their mercury-in-glass thermometer of 1/2°F accuracy. The Department of Agriculture thermometer is traceable to the University of Wisconsin using a platinum wire resistor which is certified by N.B.S.

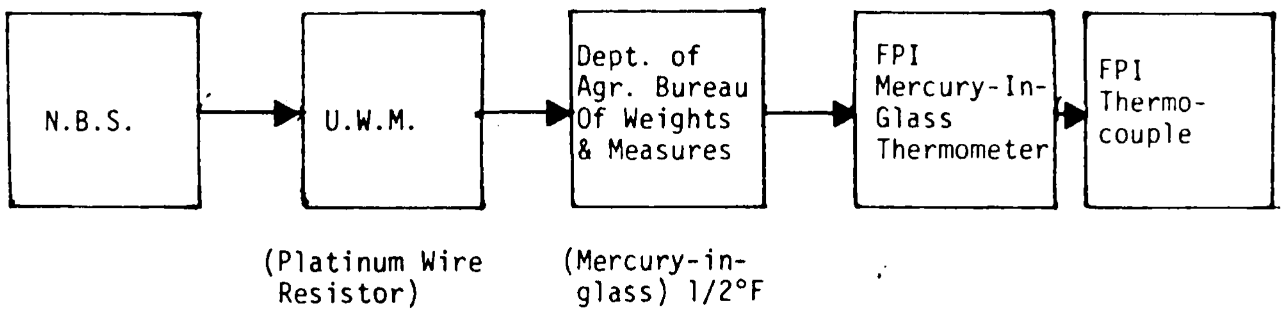



Figure 2.8.2

The error is our laboratory reference standard as propogated through above chain is 1°F.

### 2.8.3 Procedure of Calibration

Before calibration, the wire extension leads on each thermocouple were measured and length recorded to insure that the length used during calibration will be the same length used during actual usage of thermocouple. Thermocouple #0 was hooked to channel 0 on the DAS (Data Acquisition System). Thermocouple #1 was hooked to channel 1 on the DAS.

The two thermocouples and FPI glass thermometer #673650 were mounted on a ring stand and lowered into a constant temperature water bath. The thermocouples were placed close to the thermometer and at the same level. A variable speed mixer was also used to insure uniform temperature of the water.

## 2.8 Temperature Calibration

### 2.8.1 Introduction

There are several methods for temperature measurements, such as mercury-in-glass thermometers, dissimilar metal as in a thermocouple and the more expensive kind such as a vapor pressure thermometer. We use thermocouples to the greatest extent in our lab and have mercury-in-glass thermometers traceable to N.B.S. as reference standards for the calibration of these thermocouples.

Definitions and Principles
Temperature is defined as the degree or intensity of heat possessed by a substance shown by a thermometer. The thermometer most people think of is the mercury-in-glass thermometer which consists of a long thin wall glass tube sealed at both ends. At the end of this sealed tube is a well where the mercury is stored, the space the mercury has not yet occupied is filled with a dry inert gas which keeps the mercury from separating. A scale is then provided to indicate the height the mercury rises which is proportional to the temperature the bulb is measuring. One of the greatest drawbacks of these instruments is that they are very fragile.

At the institute we use the thermocouples which are more rugged and can withstand pressures greater than the glass thermometers.

The thermocouple consists of an iron wire for one conductor and a constantan wire for the other conductor. The two wires are joined together in a capillary tube which is called the measuring junction. The wires between the measuring junction and the instrumentation are called the leads. They consist of one iron wire and one constantan wire. Care should be taken to connect the iron wire lead to the iron wire from the measuring junction. If not, readings will go down instead of up when heating the measuring junction. The leads are then connected to the back of the Data Acquisition System (DAS) which has a built-in reference junction.

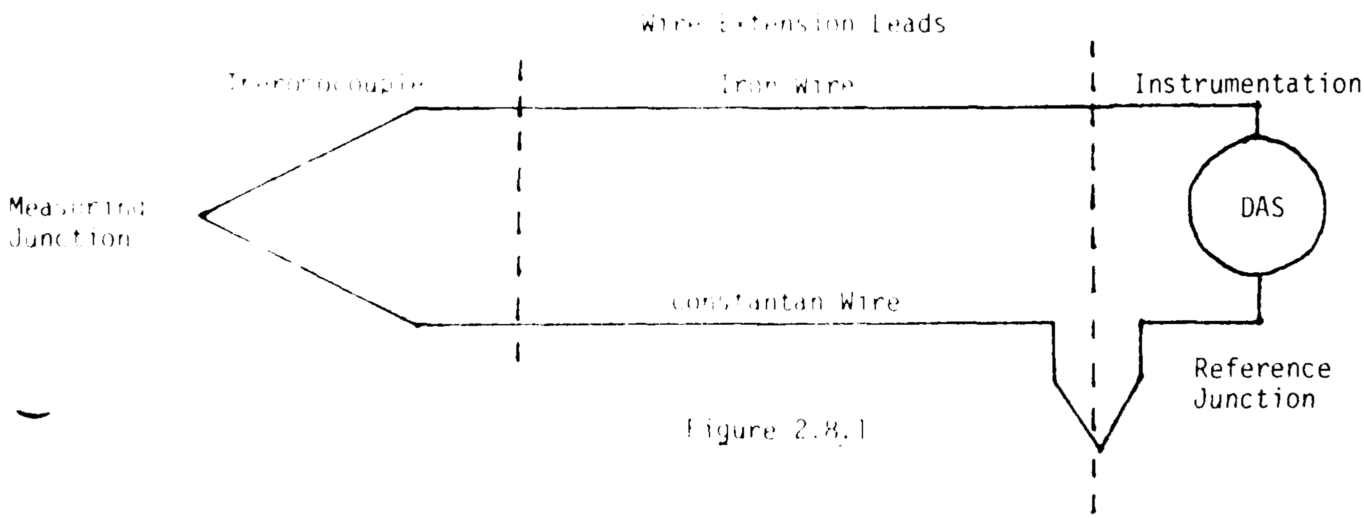



Figure 2.8.1

For angles approaching 90°, the Cot (θ) approaches $\Delta\theta$, therefore:

$$\frac{\Delta T}{T} = \frac{\Delta r}{r} + \frac{\Delta f}{f} + 2(\Delta\theta)^2$$

When θ is in radians and $\Delta\theta$ is the departure from 90°.

From the Wisconsin Department of Agriculture we know that the total uncertainty in the torque arm length is about $\pm$ 0.005 inches out of 15 inches, thus

$$\frac{\Delta r}{r} + \frac{.005}{15.00} \times 100 = .033\% \text{ of FS}$$

From results of calibrating the load cells,

$$\frac{\Delta f}{f} = \frac{.122 \text{ lb}}{75.375 \text{ lb}} = .162\% \text{ of FS}$$

It is estimated that the total angular misalignment of each cylinder does not exceed 1°, so,

$$\Delta\theta \quad .01745 \text{ radians}$$

then,

$$2\ (\Delta\theta)^2 = 2 \times (.01745)^2 = 0.0006 = .06\%.$$

Now, total error in torque,

$$\frac{\Delta T}{T} = 0.033\% + 0.162\% + .06\% = 0.255\% \text{ of full scale}$$

which is 5.1 in lbs.

2.7.6.2 Uncertainty of Working Instrument

8.75 in lbs.

3. The initial angular misalignment between the center line of the loading cylinder and the torque arm radius (not to be confused with the change in angle caused by deflection under load, a phenomenon which was corrected mathematically).

To evaluate the compsite uncertainty, it is necessary to derive the equations which dictate the means in which the individual error contributors combine. We start with the definition of torque, which is the vector cross-product of torque arm length and applied force. In our case, there are two forces and two arm lengths:

$$T = r_1 f_1 \sin\theta_1 + r_2 f_2 \sin\theta_2$$

To obtain the total uncertainty in torque, $\Delta T$, from the individual contributors, we find the six partial derivatives. That is

$$\Delta T = \frac{\partial T}{\partial r_1}\Delta r_1 + \frac{\partial T}{\partial f_1}\Delta f_1 + \frac{\partial T}{\partial \theta_1}\Delta\theta_1 + \frac{\partial T}{\partial r_2}\Delta r_2 + \frac{\partial T_2}{\partial f^2}\Delta f_2 + \frac{\partial T}{\partial \theta_2}\Delta\theta_2$$

Substitution yields

$$\Delta T = f_1 \sin\theta_1 \;\Delta r_1 + r_1 \sin\theta_1 \;\Delta f_1 + r_1 f_1 \cos\theta_1 \;\Delta\theta_1 + f_2 \sin\theta_2 \;\Delta r_2 + r_1 \sin\theta_2 \;\Delta f_2 + r_2 f_2 \cos\theta_2 \;\Delta\theta_2$$

To obtain the fractional error, we divide both sides by the total torque, but making use of the fact that the system is nearly symmetrical, that is

$$T = r_1 f_1 \sin\theta + r_2 f_2 \sin\theta_2 \approx 2r_1 f_1 \sin\theta_1 \approx 2r_2 f_2 \sin\theta_2$$

Now, by dividing:

$$\Delta T = \frac{\Delta r_1}{2r_1} + \frac{\Delta f_2}{2f_2} + \frac{\cos\theta_1}{\sin\theta_1}\Delta\theta_1 + \frac{\Delta r_2}{2r_2} + \frac{\Delta f_2}{2f_2} + \frac{\cos\theta_2}{\sin_2}\Delta\theta_2$$

Also, because $r_1 \approx r_2$, $f_1 \approx f_2$ and $\theta_1 \approx \theta_2$,

$$\Delta T = \frac{\Delta r}{r} + \frac{\Delta f}{f} + 2(\cot\theta)(\Delta\theta)$$

Final processing of the data indicated that this method was of satisfactory accuracy.

When the target value was achieved, the output of the torque transducer was recorded, along with the outputs of both load cells, and the deflection of the torque transducer. The deflection was caused by the twisting of the torque shaft as the load was applied.

Deflection was measured with a magnifying glass and machinist scale with 1/64" divisions. This method was repeated for all the increasing and decreasing increments. The procedure was repeated for a total of 5 trials.

### 2.7.5 Results

#### 2.7.5.1 Processing of Raw Data

Raw calibration data was processed in order to correct for the change in angle between the line of action of the air cylinder rods and torque arm radius line which passes through the center of the torque shaft, since perpendicularity will not be maintained as the torque shaft twists and the arm deflects. Also, the composite net applied torque was calculated from

$$T = f_1 r_1 + f_2 r_2$$

where $f_1$ and $f_2$ are the two applied forces as measured using the load cells and $r_1$ and $r_2$ are the effective torque arm lengths to the right and left of the center. A third order mathematical model was prepared as described in appendix G, annex C. The $2\sigma$ spead was found to be 0.122 lb.

### 2.7.6 Conclusion

The torque rig design is judged to be accurate for most fluid power applications, however, the process is tedious at best. The horizontal torquing plane appears to offer its greatest potential when calibrating larger torque shafts which might otherwise require tons of dead weights.

2.7.6.1 Estimated Uncertainty of the Torque Calibration Rig. There are three major error contributers to the torque calibration:

1. Uncertainty in the length of the torque arms.

2. Uncertainty in the force as determined from the load cell calibration.

APPENDIX B

FREQUENCY AND TIME CALIBRATION DATA

## REFERENCE ADDRESSES

Howard W. Sams and Co., Inc.
4300 West 62nd Street
Indianapolis, Indiana 46208

National Bureau of Standards
Time and Frequency Division
Boulder, Colorado 80303

## 5. WEEKLY TELEVISION FREQUENCY TRANSFER MEASUREMENTS USING THE COLOR SUBCARRIER

These data are furnished for users who are making frequency transfer calibrations using the television network 3.58 MHz color subcarrier signal. This signal is controlled during network programming by atomic frequency standards located at each of the major U. S. television network originating studios (ABC uses cesium standards; NBC and CBS use rubidium standards). These network standards are low with respect to UTC(NBS) by about minus 3000 parts in $10^{11}$ ($-3000 \times 10^{-11}$).

NBS estimated uncertainty of these measurements is $\pm 4 \times 10^{-12}$, except for ABC which has an estimated uncertainty of $\pm 2 \times 10^{-12}$. However, users of the color subcarrier should not expect measurement uncertainty as small as quoted since the NBS measurements are based on averaging approximately 150 hours of data per week per network. Measurement uncertainty as a function of averaging time that may be reasonably expected is as follows:

| AVERAGING TIME: | 10 seconds | 100 seconds | 15 minutes | 30 minutes | 24 hours |
|---|---|---|---|---|---|
| MEASUREMENT UNCERTAINTY: | $3 \times 10^{-10}$ | $6 \times 10^{-11}$ | $2 \times 10^{-11}$ | $1.5 \times 10^{-11}$ | $6 \times 10^{-12}$ |

Measurements can be made only on programs originating from the network studios in Los Angeles (West Coast) or New York City (East Coast). East Coast data are for those users in the Eastern, Central, and Mountain Time Zones. West Coast data are only for those users in the Pacific Time Zone.

| MEASUREMENT PERIOD 1978 | AVERAGE RELATIVE FREQUENCY (in parts in $10^{11}$) EAST COAST NBC | CBS | ABC | WEST COAST NBC | CBS* | ABC |
|---|---|---|---|---|---|---|
| 30 JULY - 5 AUG. | -3001.0** | -3001.2 | -2999.9 | -3007.2 | -3015.2 | -2999.8 |
| 6 AUG. - 12 AUG. | -3001.9** | -3001.2 | -2999.9 | -3007.8 | -3015.5 | -2999.9 |
| 13 AUG. - 19 AUG. | -3002.9** | -3001.0 | -2999.9 | -3008.2 | -3015.8 | -3000.0 |
| 20 AUG. - 26 AUG. | -3003.6** | -3001.1 | -2999.9 | -3008.5 | -3015.7 | -2999.9 |
| 27 AUG. - 2 SEPT. | -3006.2** | -3001.0 | -2999.8 | -3008.8 | -3016.0 | -3000.0 |

For information on how to use this frequency transfer method, write: Time and Frequency Division, NBS, Boulder, Colorado 80303.

*The CBS station in Los Angeles is now using a frame synchronizer on the incoming network line. Therefore, the color subcarrier for CBS West Coast is no longer available to users in the Los Angeles area. The published CBS West Coast data are derived from Line-10 measurements made by the Hewlett-Packard Company, Santa Clara, California.

**Uncertainty of the NBC data is approximately $\pm 2 \times 10^{-11}$.

## 6. BROADCAST OUTAGES OVER 5 MINUTES AND WWVB PHASE PERTURBATIONS

| STATION | OUTAGES AUG. 1978 | MJD | BEGAN (UTC) | ENDED (UTC) | FREQUENCY | PHASE PERTURBATIONS WWVB 60 kHz AUG. 1978 | MJD | BEGAN (UTC) | ENDED (UTC) |
|---|---|---|---|---|---|---|---|---|---|
| | | | NONE | | | | NONE | | |

## Frequency Counter Calibration

The ABC network color subcarrier signal from the week of August 27 to September 2, 1978 and a Singer Model HE 8020 S/N 101095 were used to calibrate four Simpson Model 7016 Frequency Counters and Timers.

Color Subcarrier Frequency 3,579,545 HZ

ABC Network Average Relative Frequency for the week of August 27 to September 2, 1978 -

$$2999.8 \times 10^{-11} \text{ HZ}$$

Corrected Color Subcarrier Frequency used for calibration -

$$3{,}579{,}545 - (2999.8 \times 10^{-11})(3579545) = 3{,}579{,}545 \text{ HZ}$$

| Counter No. | Counter Reading Frequency HZ | Color Subcarrier Frequency HZ | Error HZ |
|---|---|---|---|
| 1985 | 3,579,549 | 3,579,545 | + 4 |
| 3869 | 3,579,554 | 3,579,545 | + 9 |
| 3870 | 3,579,548 | 3,579,545 | + 3 |
| 3874 | 3,579,548 | 3,579,545 | + 3 |

Uncertainty of Reference Standard:

$$3579545 \times 3 \times 10^{-10} = 1.1 \times 10^{-3} \text{ Hz}$$

Uncertainty of Working Instrument:

$$\text{No. of Counts} = f \times \text{Gate Time}$$

$$\text{Gate Time} = \frac{\text{No. of Counts}}{f\ ref} = \frac{f\ ref + f\ error}{f\ ref}$$

$$= \frac{f\ ref}{f\ ref} + \frac{f\ error}{f\ ref} = 1 + \frac{f\ error}{f\ ref}$$

$$\text{Error in Gate Time} = 1 - \text{Gate Time} = \frac{f\ error}{f\ ref}$$

Counter No. 1985

$$\text{Error in Gate Time} = \frac{4}{3579549} = 1.1174 \times 10^{-6} \text{ sec}$$

Counter No. 3869

$$\text{Error in Gate Time} = \frac{9}{3579549} = 2.5142 \times 10^{-6} \text{ sec}$$

Counter No. 3870 + 3874

$$\text{Error in Gate Time} = \frac{3}{3579549} = 8.3809 \times 10^{-7} \text{ sec}$$

# APPENDIX C

## FLOW CALIBRATION DATA

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Calibration of Laboratory Flow rate
Reference Standard

PROJECT NO. 50560
DATE 3-19-79
TECHNICIAN J.T.M.

DESCRIPTION Repeatability Test of Upper and Lower
Triggering Level Switches

COMMENTS

INSTRUMENTATION
Starrett
Machinists Scale

Upper Triggering Level | Lower Triggering Level

| Trail # | Ref. Distance INS | Ave. INS | Dev. INS | | | Trail # | Ref. Distance INS | Ave. INS | Dev. INS |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.187 | 2.24 | - .053 | | | 1 | 1.031 | 1.722 | - .691 |
| 2 | 2.750 | 2.24 | .510 | | | 2 | 2.063 | 1.722 | .341 |
| 3 | 1.906 | 2.24 | - .334 | | | 3 | 2.406 | 1.722 | .684 |
| 4 | 1.875 | 2.24 | - .365 | | | 4 | 2.813 | 1.722 | 1.091 |
| 5 | 1.50 | 2.24 | - .740 | | | 5 | 3.063 | 1.722 | 1.341 |
| 6 | 1.094 | 2.24 | -1.146 | | | 6 | .844 | 1.722 | - .878 |
| 7 | 3.219 | 2.24 | .979 | | | 7 | .219 | 1.722 | -1.503 |
| 8 | 2.313 | 2.24 | .073 | | | 8 | 1.406 | 1.722 | - .316 |
| 9 | 2.313 | 2.24 | .073 | | | 9 | 1.531 | 1.722 | - .191 |
| 10 | 3.250 | 2.24 | 1.01 | | | 10 | 1.844 | 1.722 | - .122 |
| | | | | | | | | | |
| | 2σ = | 1.392 in. | | | | | 2σ = | 1.79 in. | |

## TOTAL VOLUME CALCULATIONS

$$V = 41 \text{ gal} \times 231 \frac{\text{in}^3}{\text{gal}} - \left(2000\text{cc} \times \frac{.06102 \text{ in}^3}{\text{cc}}\right) - V \text{ tube}$$

$$V \text{ tube} = \Delta y \, \pi \frac{1.25^2}{4} \qquad \Delta y = 12.840 \text{ in}$$

$$V \text{ tube} = 12.340 \left(\pi \frac{1.25^2}{4}\right) = 15.78 \text{ in}^3$$

$$V \text{ total} = 9471 \text{ in}^3 - 122 \text{ in}^3 - 15.78 \text{ in}^3 = 9333.22 \text{ in}^3$$

$$V \text{ total} = 9333.22 \text{ in}^3 = 40.40 \text{ gals}$$

## REPEATABILITY ERROR

$$\left(\frac{\text{range top}}{2} + \frac{\text{range bottom}}{2}\right) \times \pi \frac{1.25^2}{4}$$

$$= \left(\frac{2.156}{2} + \frac{2.187}{2}\right) \times 1.230$$

$$= (1.078 + 1.094) \times 1.230 = 2.672 \text{ in}^3$$

$$\text{error} = \left(\frac{2.672 \text{ in}^3}{9333.22}\right) \times 100 = .0286\%$$

repeatability error = .0286%

## VOLUME UNCERTAINTY

upper triggering level

$$2\sigma = 1.392 \text{ in} \qquad V = \pi \frac{1.25^2}{4} \times 2\sigma$$

$$V = \pi \frac{1.25^2}{4} \times 1.392 = 1.708 \text{ in}^3$$

lower triggering level

$$2\sigma = 1.79 \text{ in} \qquad V = \pi \frac{1.25^2}{4} \times 2\sigma$$

$$V = \pi \frac{1.25^2}{4} \times 1.79 = 2.197 \text{ in}^3$$

total uncertainty = $1.708\ in^3 + 2.197\ in^3 = 3.905\ in^3$

volume uncertainty = $3.905\ in^3$

error = $\frac{3.905}{9333.22} \times 100 = .0418\%$

READABILITY ERROR OF FIVE GALLON SERAPHIN BUCKET

From Appendix G, Annex D

$$RE = \frac{2 \times \text{value of smallest scale div.}}{R_{Fl} + 2}$$

$$R_{Fl} = 3\ (\ 1 - e^{.5-1.1w})$$

w = width of smallest division

w = 1 cu. in. = 2 mm

$$R_{Fl} = 3\ (\ 1 - e^{-1.7}) = 3\ (\ 1 - .183\ )$$

$$R_{Fl} = 2.45$$

$$RE = \frac{2 \times 1\ in^3}{2.45 + 2} = .45\ in^3$$

total readability error for nine buckets which were emptied out of the flow calibrator

$$RE = .45\ in^3 \times 9 = 4.05\ in^3$$

error = $\frac{4.05}{9333.22} \times 100 = .0434\%$

THERMAL EXPANSION ERROR

diameter at calibration time = 22.500 in

diameter at run time = 22.502 in

$$\text{volume} = \frac{\pi D^2}{4}\ (\ 23.0625\ in\ )$$

$$V_c = \frac{\pi\ 22.5^2}{4}\ (\ 23.0625\ ) = 9169.8\ in^3$$

$$V_f = \frac{\pi\ 22.502^2}{4}\ (\ 23.0625\ ) = 9171.6\ in^3$$

$$\text{error} = V_f - V_c = 9171.6 - 9169.8 = 1.8\ in^3$$

$$\frac{1.8\ in^3}{9333.22\ in^3} \times 100 = .0193$$

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Calibration of Laboratory Flowrate Reference Standard

PROJECT NO. 50560

DATE 4-20-79

TECHNICIAN J.T.M.

DESCRIPTION Clingage Test

INSTRUMENTATION

COMMENTS Used Calibration Data From 5 gpm run on 2.3 $in^3$/rev P D Meter

| Counts with Cling. | Counts without Cling. | Time Sec | Freq. HZ | Temp. °F | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 513165 | 513855 | 464.68 | 1104 | 90-100 | | | | | |
| 513158 | 513637 | 461.54 | 1111 | 90-100 | | | | | |
| 513158 | 513613 | 458.62 | 1120 | 90-100 | | | | | |
| 513197 | 513606 | 460.46 | 1115 | 90-100 | | | | | |
| 513225 | 513389 | 466.90 | 1100 | 90-100 | | | | | |
| | | | | | | | | | |
| 513181 | 513620 | 462.44 | 1110 | 95 | AVE | | | | |
| | | | | | | | | | |
| 29.5 | 165 | | | | Deviation 6 | | | | |

CLINGAGE ERROR

total volume through flowmeter

9333.22 $in^3$ with ave. pulses of 513620

$$\frac{9333.22\ in^3}{513620\ pulses} \times 120\ \frac{pulses}{rev} = 2.18\ in^3/rev$$

volume change due to clingage

$$\Delta V = (P\ cling - P\ cal) \times \frac{1\ rev}{120\ pulses} \times \frac{2.18\ in^3}{rev}$$

$$= (513620 - 513181) \times \frac{2.18}{120} = 8\ in^3$$

clingage uncertainty = 8 $in^3$

$$error = \frac{8}{9333.22} \times 100 = .0857\%$$

SUMMARY OF UNCERTAINTIES FOR LABORATORY FLOWRATE REFERENCE STANDARD

| | | |
|---|---|---|
| 1. | Uncertainty of volume of 5 gallon Seraphin bucket from NBS. | 2.079 $in^3$ |
| 2. | Uncertainty of volume of 5 gallon Seraphin bucket from Wisconsin Dept. of Agriculture. | 2.16 $in^3$ |
| 3. | Uncertainty of Seraphin bucket readability. | 4.05 $in^3$ |
| 4. | Estimated Uncertainty from FPI Technician | 4.5 $in^3$ |
| 5. | Triggering level uncertainty. (composite of upper and lower) | 3.905 $in^3$ |
| 6. | Thermal expansion uncertainty. | 1.8 $in^3$ |
| 7. | Clingage uncertainty. | 8 $in^3$ |
| | Total Uncertainty | 26.49 $in^3$ |

$$\text{Total Uncertainty} = \frac{26.49}{9333.22} \times 100 = .284\%$$

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST 2.3 in$^3$/rev P.D. Flowmeter Calibration

PROJECT NO. 50560

DATE 4-7-79

TECHNICIAN J.T.M.

DESCRIPTION

COMMENTS Mobil DTE 24 Oil at 95°F

Ave. meter factor 211.415 HZ/gpm

INSTRUMENTATION

| Trial #1 | | | | | Trial #2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Target Flow GPM | Ave Freq HZ | Run Time SEC | Total Counts | Actual Flow GPM | Target Flow GPM | Ave Freq HZ | Run Time SEC | Total Counts | Actual Flow GPM |
| 5 | 1101.5 | 465.86 | 513165 | 5.20 | 5 | 1126.6 | 455.49 | 513158 | 5.32 |
| 10 | 2144.7 | 239.35 | 513328 | 10.13 | 10 | 2178.5 | 235.65 | 513357 | 10.29 |
| 15 | 3222.5 | 159.22 | 513094 | 15.23 | 15 | 3285.9 | 156.13 | 513021 | 15.53 |
| 20 | 4261.6 | 120.35 | 512882 | 20.14 | 20 | 4187.6 | 122.49 | 512946 | 19.79 |
| 25 | 5354.2 | 95.72 | 512505 | 25.33 | 25 | 5417.7 | 94.60 | 512515 | 25.63 |
| 30 | 6395.6 | 80.09 | 512222 | 30.27 | 30 | 6327.3 | 80.94 | 512128 | 29.95 |
| 35 | 7438.2 | 68.79 | 511674 | 35.24 | 35 | 7455.7 | 68.62 | 511607 | 35.33 |
| 40 | [illegible] | 59.64 | 511509 | 40.65 | 40 | 8573.9 | 59.66 | 511518 | 40.63 |

| Trial #3 | | | | | Trial #4 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Target Flow GPM | Ave Freq HZ | Run Time SEC | Total Counts | Actual Flow GPM | Target Flow GPM | Ave Freq HZ | Run Time SEC | Total Counts | Actual Flow GPM |
| [illegible] | [illegible] | 466.18 | 513158 | 5.20 | 5 | 1120.7 | 457.91 | 513197 | 5.29 |
| [illegible] | 2169.4 | 236.58 | 513235 | 10.25 | 10 | 2151.1 | 238.56 | 513161 | 10.16 |
| 15 | 3171.3 | 161.78 | 513051 | 14.98 | 15 | 3231.1 | 158.79 | 513067 | 15.27 |
| [illegible] | [illegible] | 119.22 | 512795 | 20.33 | 20 | 4263.5 | 120.26 | 512729 | 20.16 |
| [illegible] | 5321.8 | 96.3 | 512488 | 25.17 | 25 | 5210.3 | 98.39 | 512645 | 24.64 |
| 30 | 6360.6 | 80.54 | 512284 | 30.1 | 30 | 6342.5 | 80.77 | 512281 | 30.01 |
| 35 | 7454.4 | 68.64 | 511672 | 35.32 | 35 | 7485 | 68.34 | 511529 | 35.47 |
| 40 | 8574.5 | 59.66 | 511555 | 40.63 | 40 | 8535.1 | 59.92 | 511426 | 40.46 |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST [illegible] $in^3$/rev P.D. Flowmeter [illegible]

PROJECT NO. [illegible]

DATE [illegible]

TECHNICIAN [illegible]

DESCRIPTION

COMMENTS Mobil DTE 24 Oil at 95 F

INSTRUMENTATION

Trial #5

| Target Flow GPM | Ave Freq. HZ | Run Time SEC | Total Counts | Actual Flow GPM | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | 455.78 | 513225 | 5.32 | | | | | |
| [illegible] | 2140 | 239.84 | 513234 | 10.11 | | | | | |
| [illegible] | 3247 | 158.02 | 513093 | 15.34 | | | | | |
| [illegible] | 4244.2 | 120.84 | 512865 | 20.06 | | | | | |
| [illegible] | 5344.2 | 95.93 | 512667 | 25.27 | | | | | |
| [illegible] | 6302.1 | 81.29 | 512296 | [illegible] | | | | | |
| [illegible] | 7456.5 | 68.60 | 511519 | 35.33 | | | | | |
| [illegible] | [illegible] | 59.84 | [illegible] | [illegible] | | | | | |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Elbow Load Cell Calibration

PROJECT NO. 50560
DATE 11-3-78
TECHNICIAN J.O.M.

DESCRIPTION Model 3167-100 S/N [illegible]

COMMENTS Summary of Ave. Values
(I) increasing values
(D) decreasing values

INSTRUMENTATION
Ashcroft Weights
Daytronics Amplifier
Fluke VTVM

| Weight lbs | INC Volts | DEC Volts | | Ref Value Lbs | Ind Value Volts | Conv. LB/V | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | | 0 | 0 | -- | | | |
| .361 | .034 | .032 | | .361 | .034 | 10.618 | | | |
| 6.612 | .665 | .663 | | 6.612 | .665 | 9.943 | | | |
| 12.683 | 1.293 | 1.294 | | 12.683 | 1.293 | 9.809 | | | |
| 19.114 | 1.923 | 1.922 | | 19.114 | 1.923 | 9.948 | | | |
| 25.366 | 2.557 | 2.551 | | 25.366 | 2.557 | 9.920 | | | |
| 31.617 | 3.179 | 3.180 | | 31.617 | 3.179 | 9.946 | | | |
| 37.868 | 3.808 | 3.808 | | 37.868 | 3.808 | 9.944 | | | |
| 44.119 | 4.435 | 4.436 | | 44.119 | 4.435 | 9.948 | | | |
| 50.370 | 5.063 | 5.063 | | 50.370 | 5.063 | 9.949 | | | |
| 56.621 | 5.689 | 5.689 | | 56.621 | 5.689 | 9.953 | | | |
| 62.873 | 6.315 | 6.314 | | 62.873 | 6.315 | 9.956 | | | |
| 69.124 | 6.941 | 6.941 | | 69.124 | 6.941 | 9.959 | | | |
| 75.375 | 7.566 | 7.566 | | 75.375 | 7.566 | 9.962 | | | |

Third Order Mathematical [illegible] volts

# FLUID POWER INSTITUTE
# MILWAUKEE SCHOOL OF ENGINEERING

TEST: Lebow Load Cell Calibration

PROJECT NO. 50560

DATE: 11-3-78

TECHNICIAN: J.O.M.

DESCRIPTION: Model 3167-100 s/n 518

INSTRUMENTATION
Ashcraft weights
Daytronics Amplifier
Fluke VTVM

COMMENTS

INC increasing value

DEC decreasing value

Trial #5

| Weight Lbs | INC Volts | DEC Volts | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | | | | | | | |
| .361 | .033 | .032 | | | | | | | |
| 6.612 | .665 | .663 | | | | | | | |
| 12.683 | 1.294 | 1.294 | | | | | | | |
| 1[illegible].114 | 1.924 | 1.924 | | | | | | | |
| [illegible].366 | 2.554 | 2.553 | | | | | | | |
| [illegible] | 3.183 | 3.182 | | | | | | | |
| [illegible] | 3.811 | 3.812 | | | | | | | |
| [illegible] | 4.439 | 4.440 | | | | | | | |
| [illegible] | 5.067 | 5.066 | | | | | | | |
| [illegible] | 5.695 | 5.695 | | | | | | | |
| [illegible] | 6.323 | 6.321 | | | | | | | |
| [illegible] | 6.949 | 6.949 | | | | | | | |
| [illegible] | 7.576 | 7.575 | | | | | | | |

# FLUID POWER INSTITUTE
# MILWAUKEE SCHOOL OF ENGINEERING

TEST Lebow Load Cell Calibration

PROJECT NO. 50560

DATE 11-3-78

TECHNICIAN J.O.M.

DESCRIPTION Model 3167 - 100 s/n 518

COMMENTS Cal resister value = 73.15 lbs

INC increasing value

DEC decreasing value

INSTRUMENTATION
Ashcroft weights
Daytronics Amplifier
Fluke VTVM

| | Trial #1 | | Trial #2 | | Trial #3 | | Trial #4 | | |
|---|---|---|---|---|---|---|---|---|---|
| Weight lbs | INC Volts | DEC Volts | INC Volts | DEC Volts | INC Volts | DEC Volts | INC Volts | DEC Volts | |
| 0 | 0 | 0 | 0 | -.001 | -.001 | -.001 | -.001 | 0 | |
| .361 | .041 | .039 | .024 | .023 | .038 | .032 | .032 | .034 | |
| 6.612 | .672 | .672 | .655 | .653 | .668 | .662 | .663 | .664 | |
| 12.683 | 1.301 | 1.301 | 1.283 | 1.283 | 1.295 | 1.293 | 1.294 | 1.297 | |
| 19.114 | 1.930 | 1.930 | 1.913 | 1.911 | 1.922 | 1.922 | 1.924 | 1.925 | |
| 25.366 | 2.559 | 2.559 | 2.542 | 2.540 | 2.551 | 2.551 | 2.553 | 2.554 | |
| 31.617 | 3.187 | 3.187 | 3.169 | 3.168 | 3.178 | 3.179 | 3.180 | 3.182 | |
| 37.868 | 3.814 | 3.815 | 3.797 | 3.796 | 3.806 | 3.807 | 3.810 | 3.810 | |
| 44.119 | 4.441 | 4.442 | 4.424 | 4.423 | 4.433 | 4.436 | 4.438 | 4.437 | |
| 50.370 | 5.069 | 5.069 | 5.052 | 5.051 | 5.056 | 5.063 | 5.066 | 5.064 | |
| 56.621 | 5.694 | 5.696 | 5.678 | 5.677 | 5.688 | 5.687 | 5.691 | 5.691 | |
| 62.873 | 6.321 | 6.320 | 6.301 | 6.302 | 6.313 | 6.313 | 6.316 | 6.316 | |
| 6[illegible].124 | 6.947 | 6.947 | 6.926 | 6.929 | 6.939 | 6.939 | 6.942 | 6.943 | |
| 75.375 | 7.571 | 7.572 | 7.552 | 7.552 | 7.564 | 7.564 | 7.567 | 7.567 | |

Uncertainty of Lebow Load Cell Model 3167-100 s/n 517

Reference Standard Error = .05%

Readability Error = .006%

Calibration Error = $2\sigma = .008V$

$$\frac{.008}{7.574} \times 100 = .106\%$$

Total Error = .05% + .006% + .106% = .162% = .122 lbs

Uncertainty = .122 lbs

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Elbow Load Cell Calibration | PROJECT NO. 50560
DATE 5-10-79
TECHNICIAN N.A.S.

DESCRIPTION Model 3167-100 s/n 517

INSTRUMENTATION

COMMENTS Absolute Value of Deviation from the Average

INC increasing value

DEC decreasing value

| Ave Value Volts | | Trial #4 INC Volts | Trial #4 DEC Volts | | Trial #5 INC Volts | Trial #5 DEC Volts | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | .000 | .000 | | .000 | .000 | | | |
| .029 | | .003 | .002 | | .001 | .000 | | | |
| .661 | | .003 | .001 | | .000 | .001 | | | |
| 1.291 | | .003 | .001 | | .000 | .002 | | | |
| 1.921 | | .004 | .001 | | .001 | .004 | | | |
| 2.551 | | .002 | .001 | | .002 | .005 | | | |
| 3.180 | | .002 | .000 | | .004 | .006 | | | |
| [illegible] | | .001 | .000 | | .004 | .006 | | | |
| 4.436 | | .001 | .001 | | .007 | .007 | | | |
| 5.065 | | .000 | .001 | | .009 | .010 | | | |
| 5.693 | | .000 | .001 | | .010 | .010 | | | |
| 6.32 | | .000 | .001 | | .012 | .011 | | | |
| 6.946 | | .002 | .002 | | .013 | .014 | | | |
| 7.574 | | .002 | .001 | | .015 | .014 | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | x | .004 Volts | | | | | | |
| | | | | | | | | | |
| | | δ | .004 Volts | | | | | | |
| | | | | | | | | | |
| | | 2δ | .008 Volts | | | | | | |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST: Lebow Load Cell Calibration

PROJECT NO. 50560

DATE 5-10-79

TECHNICIAN N.A.S.

DESCRIPTION Model 3167-100 s/n 517

INSTRUMENTATION

COMMENTS Absolute Value of Deviation from the Average

INC increasing values
DEC decreasing values

| Ave Value Volts | | Trial #1 INC Volts | Trial #1 DEC Volts | | Trial #2 INC Volts | Trial #2 DEC Volts | | Trial #3 INC Volts | Trial #3 DEC Volts |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | .000 | .000 | | .000 | .000 | | .000 | .000 |
| .029 | | .002 | .003 | | .001 | .001 | | .003 | .004 |
| .661 | | .001 | .002 | | .001 | .001 | | .003 | .003 |
| 1.291 | | .002 | .001 | | .002 | .001 | | .002 | .003 |
| 1.921 | | .002 | 000 | | .003 | .002 | | .003 | .004 |
| 2.551 | | .004 | .002 | | .003 | .002 | | .002 | .003 |
| 3.180 | | .006 | .002 | | .004 | .003 | | .002 | .004 |
| 3.[illegible]10 | | .006 | .004 | | .004 | .003 | | .002 | .003 |
| 4.436 | | .014 | .003 | | .003 | .003 | | .002 | .004 |
| 5.065 | | .009 | .006 | | .004 | .001 | | .001 | .003 |
| 5.693 | | .011 | .008 | | .005 | .004 | | .000 | .002 |
| 6.321 | | .011 | .010 | | .004 | .004 | | .001 | .003 |
| 6.948 | | .013 | .012 | | .005 | .004 | | .001 | .002 |
| 7.574 | | .013 | .014 | | .005 | .004 | | .001 | .000 |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST ..ebow Load Cell Calibration

PROJECT NO. 50560

DATE 11-3-78

TECHNICIAN J.O.M.

DESCRIPTION Model 3167-100 s/n 517

COMMENTS Summary of Ave Valves

INC increasing values

DEC decreasing values

INSTRUMENTATION
Ashcroft Weights
Daytronics Amplifier
Fluke VTVM

| Weignt lbs. | INC Volts | DEC Volts | | Ref. Value lbs | Ind. Value Volts | Conv. lb/V |
|---|---|---|---|---|---|---|
| 0 | 0 | -.001 | | 0 | 0 | 0 |
| .361 | .029 | .030 | | .361 | .029 | 12.448 |
| 6.612 | .661 | .667 | | 6.612 | .661 | 10.003 |
| 12.683 | 1.291 | 1.293 | | 12.683 | 1.291 | 9.964 |
| 19.114 | 1.921 | 1.923 | | 19.114 | 1.921 | 9.936 |
| 25.366 | 2.551 | 2.553 | | 25.366 | 2.551 | 9.944 |
| 31.617 | 3.180 | 3.182 | | 31.617 | 3.180 | 9.942 |
| 37.868 | 3.809 | 3.810 | | 37.868 | 3.809 | 9.942 |
| 44.[illegible] | 4.436 | 4.439 | | 44.119 | 4.436 | 9.946 |
| 50.3[illegible] | 5.065 | 5.067 | | 50.370 | 5.065 | 9.945 |
| 56.62[illegible] | 5.693 | 5.694 | | 56.621 | 5.693 | 9.946 |
| 62.[illegible] | 6.321 | 6.321 | | 62.873 | 6.321 | 9.947 |
| 69.[illegible] | 6.948 | 6.948 | | 69.124 | 6.948 | 9.949 |
| 75.[illegible] | 7.574 | 7.573 | | 75.375 | 7.574 | 9.952 |

Third Order Mathematical Error .015 Volts

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Lebow Load Cell Calibration

PROJECT NO. 50560

DATE 11-3-78

TECHNICIAN J.O.M.

DESCRIPTION Model 3167-100 s/n 517

COMMENTS

INC increasing value
DEC decreasing value

INSTRUMENTATION
Ashcroft Weights
Daytronics Amplifier
Fluke VTVM

Trial #5

| Weight lbs | INC Volts | DEC Volts |
|---|---|---|
| 0 | 0 | -.001 |
| .361 | .028 | .029 |
| 6.612 | .661 | .662 |
| 12.683 | 1.292 | 1.294 |
| 19.114 | 1.923 | 1.926 |
| 25.366 | 2.554 | 2.557 |
| 31.617 | 3.185 | 3.187 |
| 37.868 | 3.814 | 3.816 |
| 44.119 | 4.445 | 4.445 |
| 50.370 | 5.075 | 5.076 |
| 56.621 | 5.704 | 5.704 |
| 62.873 | 6.333 | 6.332 |
| 69.124 | 6.961 | 6.962 |
| 75.375 | 7.589 | 7.587 |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Lebow Load Cell Calibration

PROJECT NO. 50560

DATE 11-3-78

TECHNICIAN J.O.M.

DESCRIPTION Model 3167-100 s/n 517

COMMENTS Cal resister value 71.41 lbs

INC increasing value

DEC decreasing value

INSTRUMENTATION
Ashcroft Weights
Daytronics Amplifier
Fluke VTVM

| | Trial #1 | | Trial #2 | | Trial #3 | | Trial #4 | | |
|---|---|---|---|---|---|---|---|---|---|
| Weight lbs | INC Volts | DEC Volts | INC Volts | DEC Volts | INC Volts | DEC Volts | INC Volts | DEC Volts | |
| | | | | | | | | | |
| 0 | 0 | 0 | -.001 | 0 | 0 | -.001 | -.001 | -.001 | |
| .361 | .031 | .032 | .028 | .028 | .032 | .033 | .026 | .027 | |
| 6.612 | .662 | .663 | .660 | .660 | .664 | .664 | .658 | .660 | |
| 12.683 | 1.290 | 1.293 | 1.291 | 1.290 | 1.294 | 1.295 | 1.289 | 1.291 | |
| 19.134 | 1.920 | 1.922 | 1.919 | 1.920 | 1.925 | 1.926 | 1.918 | 1.921 | |
| 25.366 | 2.548 | 2.550 | 2.549 | 2.550 | 2.554 | 2.555 | 2.550 | 2.551 | |
| 31.617 | 3.175 | 3.179 | 3.177 | 3.178 | 3.183 | 3.185 | 3.179 | 3.181 | |
| 37.868 | 3.804 | 3.806 | 3.806 | 3.807 | 3.812 | 3.813 | 3.809 | 3.810 | |
| 44.119 | 4.424 | 4.435 | 4.435 | 4.435 | 4.440 | 4.442 | 4.437 | 4.439 | |
| 50.370 | 5.057 | 5.060 | 5.062 | 5.064 | 5.067 | 5.069 | 5.066 | 5.067 | |
| 56.621 | 5.683 | 5.686 | 5.689 | 5.690 | 5.694 | 5.696 | 5.694 | 5.695 | |
| 62.873 | 6.310 | 6.311 | 6.317 | 6.317 | 6.322 | 6.324 | 6.321 | 6.322 | |
| 69.124 | 6.935 | 6.936 | 6.943 | 6.944 | 6.949 | 6.950 | 6.950 | 6.950 | |
| 75.375 | 7.56[illegible] | 7.566 | 7.569 | 7.570 | 7.575 | 7.574 | 7.576 | 7.575 | |
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APPENDIX D

LOAD CELL AND TORQUE SHAFT CALIBRATION DATA

## Uncertainty of 10 $in^3$/rev P.D. Flowmeter

deviation $2\sigma$ = .4669 hz

ave meter factor = 31.334 hz/gpm

random error = $2\sigma$ = .4669 hz

readability error = 1 hz

reference standard error = .286%Q

total error = $\dfrac{1.4669 \text{ hz}}{31.334 \text{ hz/gpm}}$ + .286%Q

instrument uncertainty = .047 gpm + .286%Q

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

ST 10 in$^3$/rev P.D. Flowmeter Calibration

PROJECT NO. 50560

DATE 3-21-79

TECHNICIAN J.T.M.

DESCRIPTION

INSTRUMENTATION

COMMENTS Mobil DTE 24 Oil at 95° F

| Trial #5 | | | | | Trial #6 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Target Flow GPM | Ave Freq HZ | Run Time SEC | Total Counts | Actual Flow FPM | Target Flow FPM | Ave Freq HZ | Run Time SEC | Total Counts | Actual Flow GPM |
| 5 | 168 | 451.61 | 75887 | 5.37 | 5 | 168 | 451.53 | 75876 | 5.37 |
| 10 | 319.8 | 237.25 | 75882 | 10.22 | 10 | 319.8 | 237.28 | 75875 | 10.22 |
| 15 | 476.4 | 159.49 | 75988 | 15.19 | 15 | 476.3 | 159.51 | 75974 | 15.19 |
| 20 | 636.8 | 119.30 | 75969 | 20.32 | 20 | 636.8 | 119.27 | 75957 | 20.34 |
| 25 | 825.1 | 92.02 | 75926 | 26.34 | 25 | 825.2 | 92.05 | 75958 | 26.34 |
| 30 | 963.9 | 78.78 | 75940 | 30.77 | 30 | 964.3 | 78.75 | 75937 | 30.78 |
| 35 | 1136.7 | 66.78 | 75910 | 36.3 | 35 | 1135.5 | 66.85 | 75910 | 36.26 |
| 40 | 1288.5 | 58.95 | 75957 | 41.12 | 40 | 1287.5 | 58.99 | 75952 | 41.10 |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST 10 $in^3$/rev P.D. Flowmeter Calibration

PROJECT NO. 50560

DATE 3-21-79

TECHNICIAN J.T.M.

DESCRIPTION

INSTRUMENTATION

COMMENTS Mobil DTE 24 Oil at 95 F

ave meter factor = 31.334 hz/gpm

| Trial #1 | | | | | Trial #2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Target Flow GPM | Ave Freq HZ | Run Time SEC | Total Counts | Actual Flow GPM | Target Flow GPM | Ave Freq HZ | Run Time SEC | Total Counts | Actual Flow GPM |
| 5 | 167.5 | 453.01 | 75897 | 5.35 | 5 | 167.8 | 452.32 | 75893 | 5.36 |
| [illegible] | 320.2 | 237.08 | 75911 | 10.23 | 10 | 320 | 237.37 | 75921 | 10.22 |
| 15 | 482.4 | 157.62 | 76038 | 15.38 | 15 | 481.4 | 157.91 | 76013 | 15.35 |
| 20 | 633.8 | 119.91 | 75993 | 20.22 | 20 | 637.5 | 119.17 | 75967 | 20.34 |
| 25 | 809.4 | 93.85 | 75965 | 25.83 | 25 | 825.4 | 92.12 | 76032 | 26.32 |
| 30 | 962.4 | 78.97 | 76001 | 30.69 | 30 | 963.8 | 78.80 | 75948 | 30.76 |
| 35 | 1120.9 | 67.74 | 75928 | 35.79 | 35 | 1135 | 66.91 | 75943 | 36.23 |
| 40 | 1276 | 59.50 | 75922 | 40.74 | 40 | 1286.8 | 58.99 | 75908 | 41.10 |

| Trial #3 | | | | | Trial #4 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Target Flow GPM | Ave Freq HZ | Run Time SEC | Total Counts | Actual Flow GPM | Target Flow GPM | Ave Freq HZ | Run Time SEC | Total Counts | Actual Flow GPM |
| 5 | 168.1 | 451.54 | 75889 | 5.37 | 5 | 168.4 | 450.74 | 75885 | 5.38 |
| 10 | 319.9 | 237.22 | 75881 | 10.22 | 10 | 319.7 | 237.37 | 75885 | 10.21 |
| 15 | 477.4 | 159.28 | 76044 | 15.22 | 15 | 476.9 | 159.34 | 75995 | 15.21 |
| 20 | 636.6 | 119.34 | 75967 | 20.31 | 20 | 636.6 | 119.31 | 75953 | 20.31 |
| 25 | 825.2 | 92.07 | 75973 | 26.33 | 25 | 824.9 | 92.03 | 75920 | 26.34 |
| 30 | 963.9 | 78.80 | 75959 | 30.76 | 30 | 963.9 | 78.79 | 75949 | 30.76 |
| 35 | 1135.3 | 66.86 | 75903 | 36.25 | 35 | 1135.3 | 66.86 | 75904 | 36.26 |
| 40 | 1287.1 | 58.99 | 75927 | 41.[illegible] | 40 | 1287.9 | 58.98 | 75961 | 41.10 |

Uncertainty of 2.3 $in^3$/rev P.D. Flowmeter

deviation $2\sigma$ = 2.49 hz

ave. meter factor 211.415 hz/gpm

random error = $2\sigma$ = 2.49 hz

readability error = 1 hz

reference standard error = .286 of Q

total error = $\dfrac{3.49 \text{ hz}}{211.415 \text{ hz/gpm}}$ + .286 Q

instrument uncertainty = .0165 gpm + .286 Q

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Lebow Load Cell Calibration

PROJECT NO. 50566

DATE 5-10-79

TECHNICIAN N.A.S.

DESCRIPTION Model 3167-100 s/n 518

INSTRUMENTATION

COMMENTS Absolute Value of Deviation from the Average
INC increasing values
DEC decreasing values

| Ave Value Volts | | Trial #1 INC Volts | Trial #1 DEC Volts | | Trial #2 INC Volts | Trial #2 DEC Volts | | Trial #3 INC Volts | Trial #3 DEC Volts |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | .000 | .000 | | .000 | .000 | | .000 | .000 |
| .634 | | .008 | .006 | | .009 | .010 | | .005 | .001 |
| .665 | | .008 | .008 | | .009 | .011 | | .004 | .002 |
| 1.293 | | .007 | .007 | | .011 | .011 | | .001 | .001 |
| 1.923 | | .007 | .007 | | .010 | .012 | | .001 | .001 |
| 2.557 | | .007 | .007 | | .010 | .012 | | .001 | .001 |
| 3.179 | | .007 | .007 | | .011 | .012 | | .002 | .001 |
| 3.808 | | .006 | .007 | | .011 | .012 | | .002 | .001 |
| 4.435 | | .006 | .007 | | .011 | .012 | | .002 | .001 |
| 5.063 | | .006 | .006 | | .011 | .012 | | .002 | .000 |
| 5.689 | | .005 | .007 | | .011 | .012 | | .001 | .002 |
| 6.315 | | .006 | .005 | | .014 | .013 | | .002 | .002 |
| 6.941 | | .006 | .006 | | .015 | .012 | | .002 | .002 |
| 7.566 | | .005 | .006 | | .014 | .014 | | .002 | .002 |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Lebow Load Cell Calibration

PROJECT NO. 50560

DATE 5-1[illegible]-79

TECHNICIAN N.A.S.

DESCRIPTION Model 3167-100 s/n 518

INSTRUMENTATION

COMMENTS Absolute value of Deviation from the Average

INC increasing value

DEC decreasing value

| | | Trial #4 | | | Trial #5 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ave Value Volts | | INC Volts | DEC Volts | | INC Volts | DEC Volts | | | |
| 0 | | .000 | .000 | | .000 | .000 | | | |
| .034 | | .001 | .002 | | .000 | .001 | | | |
| .665 | | .001 | .002 | | .001 | .001 | | | |
| 1.293 | | .000 | .001 | | .000 | .000 | | | |
| 1.923 | | .001 | .002 | | .001 | .001 | | | |
| 2.557 | | .001 | .002 | | .002 | .001 | | | |
| 3.179 | | .000 | .002 | | .003 | .002 | | | |
| 3.808 | | .002 | .002 | | .003 | .004 | | | |
| 4.435 | | .003 | .002 | | .004 | .005 | | | |
| 5.063 | | .003 | .001 | | .004 | .003 | | | |
| 5.689 | | .002 | .002 | | .006 | .006 | | | |
| 6.315 | | .001 | .001 | | .008 | .006 | | | |
| 6.941 | | .001 | .002 | | .008 | .008 | | | |
| 7.566 | | .001 | .001 | | .010 | .009 | | | |
| | | | | | | | | | |
| | | $\bar{x}$ | .005 Volts | | | | | | |
| | | | | | | | | | |
| | | $\sigma$ | .004 Volts | | | | | | |
| | | | | | | | | | |
| | | $2\sigma$ | .008 Volts | | | | | | |

Uncertainty of Lebow Load Cell Model 3167-100 s/n 518

Reference Standard Error = .05% = .0377 lbs

Readability Error = .006

Calibration Error = 2 $\sigma$ = .008V

$$\frac{.008V}{7.566V} \times 100 = .106\%$$

Total Error = .05 + .006% + .106%

= .162 = .122 lbs

Uncertainty = .122 lbs

Uncertainty of Laboratory Torque Reference Standard

Torque Arm Length Uncertainty

.010 in $\frac{.010}{30.055} \times 100 = .033\%$

Load Cell Calibration Uncertainty

.162%

Angular Misalignment Uncertainty

$2(\Delta\theta)^2 \times 100 \qquad \Delta\theta = 1^\circ = .01745$ radians

$= 2(.01745)^2 \times 100 = .06\%$

Total Uncertainty = .033 + .162 + .06

.255% = 5.1 in lbs

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Himmelstein 2000 in lb
Torque Shaft Calibration

PROJECT NO. 50560
DATE 11-14-78
TECHNICIAN N.A.S.
J.Q.M.

DESCRIPTION Daytronics 300D and Fluke VTVM for Load Cells.
Daytronics 3278 for Torque Shaft

INSTRUMENTATION
Daytronics Amplifiers
Fluke VTVM

COMMENTS
A-load cell 517 length 15.022 ins
B-load cell 518 length 15.033 inS
Cal resistor value - 2016 IN LBS

Trial #1 Increasing Decreasing

| Target | A | B | Def. | A | B | Def. | | Calc. | Torque |
|---|---|---|---|---|---|---|---|---|---|
| Torque | Force | Force | of Beam | Force | Force | of Beam | | INC | DEC |
| IN LBS | Volts | Volts | IN | Volts | Volts | IN | | IN LBS | IN LBS |
| 0 | 0 | 0 | 0 | .020 | -.007 | 0 | | 0 | 0 |
| 200 | .734 | .583 | .063 | .593 | .719 | .094 | | 197.90 | 197.17 |
| 400 | 1.379 | 1.275 | .125 | 1.290 | 1.357 | .156 | | 398.82 | 397.78 |
| 600 | 2.010 | 1.972 | .203 | 1.835 | 2.151 | .234 | | 598.39 | 599.01 |
| 800 | 2.616 | 2.708 | .250 | 2.493 | 2.828 | .297 | | 800.07 | 799.63 |
| 1000 | 3.243 | 3.415 | .328 | 3.208 | 3.452 | .359 | | 1000.54 | 1000.89 |
| 1200 | 3.931 | 4.072 | .391 | 3.974 | 4.034 | .422 | | 1202.66 | 1203.41 |
| 1400 | 4.623 | 4.717 | .453 | 4.670 | 4.650 | .484 | | 1403.57 | 1400.56 |
| 1600 | 5.291 | 5.393 | .531 | 5.467 | 5.228 | .547 | | 1605.59 | 1607.18 |
| 1800 | 5.891 | 6.138 | .594 | 6.211 | 5.827 | .609 | | 1807.67 | 1808.99 |
| 2000 | 6.642 | 6.740 | .656 | | | .656 | | 2010.99 | |
| | | | | | | | | | |
| Trial #2 | Increasing | | | Decreasing | | | | | |
| 0 | 0 | 0 | 0 | .025 | -.007 | 0 | | 0 | 0 |
| 200 | 731 | .592 | .078 | .599 | .725 | .094 | | 198.81 | 198.97 |
| 400 | 1.363 | 1.293 | .156 | 1.140 | 1.509 | .156 | | 399.13 | 398.10 |
| 600 | 2.031 | 1.968 | .188 | 1.848 | 2.146 | .219 | | 600.95 | 600.21 |
| 800 | 2.641 | 2.694 | .250 | 2.598 | 2.735 | .281 | | 801.72 | 801.42 |
| 1000 | 3.305 | 3.372 | .313 | 3.321 | 3.356 | .359 | | 1003.39 | 1003.39 |
| 1200 | 3.939 | 4.079 | .391 | 4.018 | 4.000 | .422 | | 1204.91 | 1204.90 |
| 1400 | 4.573 | 4.780 | .453 | 4.740 | 4.614 | .484 | | 1405.53 | 1405.67 |
| 1600 | 5.197 | 5.497 | .516 | 5.519 | 5.187 | .547 | | 1607.06 | 1608.83 |
| 1800 | 5.990 | 6.061 | .594 | 6.237 | 5.828 | .594 | | 1803.46 | 1813.05 |
| 2000 | 6.638 | 6.755 | .656 | | | .656 | | 2012.64 | |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Himmelstein 2000 in lb Torque Shaft Calibration

PROJECT NO. 50560

DATE 11-14-78

TECHNICIAN N.A.S.
J.Q.M.

DESCRIPTION Daytronics 300D and Fluke VTVM for Load Cells.
Daytronics 3278 for Torque Shaft

INSTRUMENTATION
Daytronics Amplifiers
Fluke VTVM

COMMENTS
A - load cell 517 length 15.022 in
B - load cell 518 length 15.033 in
Cal resister value 2016 IN LBS

| Trial #3 | | Increasing | | Decreasing | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Target Torque In LBS | A Force Volts | B Force Volts | Def. of Beam IN | A Force Volts | B Force Volts | Def. of Beam IN | | Calc. INC IN LBS | Torque DEC IN LBS |
| 0 | .010 | -.011 | 0 | .020 | -.015 | 0 | | 0 | 0 |
| 200 | .724 | .593 | .078 | .655 | .651 | .094 | | 197.90 | 196.26 |
| 400 | 1.388 | 1.267 | .156 | 1.306 | 1.326 | .156 | | 398.97 | 395.52 |
| 600 | 2.021 | 1.964 | .188 | 1.961 | 2.003 | .219 | | 598.84 | 595.69 |
| 800 | 2.674 | 2.643 | .250 | 2.547 | 2.759 | .281 | | 799.01 | 797.37 |
| 1000 | 3.298 | 3.346 | .313 | 3.276 | 3.367 | .359 | | 998.43 | 998.28 |
| 1200 | 3.960 | 4.030 | .391 | 3.958 | 4.029 | .422 | | 1200.70 | 1200.25 |
| 1400 | 4.598 | 4.717 | .453 | 4.721 | 4.606 | .484 | | 1399.82 | 1401.61 |
| 1600 | 5.220 | 5.428 | .516 | 5.451 | 5.210 | .547 | | 1600.14 | 1602.07 |
| 1800 | 5.947 | 6.044 | .594 | 6.152 | 5.851 | .594 | | 1801.95 | 1803.73 |
| 2000 | 6.600 | 6.733 | .656 | | | .656 | | 2003.62 | |

| Trial #4 | | Increasing | | Decreasing | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | .018 | -.017 | 0 | .022 | -.016 | 0 | | 0 | 0 |
| 200 | .720 | .580 | .078 | .511 | .784 | .109 | | 195.35 | 194.62 |
| 400 | 1.411 | 1.226 | .125 | 1.033 | 1.596 | .156 | | 396.42 | 395.10 |
| 600 | 2.156 | 1.811 | .203 | 1.821 | 2.142 | .234 | | 596.12 | 595.56 |
| 800 | 2.826 | 2.476 | .266 | 2.410 | 2.891 | .297 | | 796.74 | 796.63 |
| 1000 | 3.479 | 3.156 | .328 | 3.099 | 3.533 | .359 | | 997.06 | 996.65 |
| 1200 | 4.044 | 3.928 | .438 | 3.774 | 4.208 | .422 | | 1197.99 | 1199.52 |
| 1400 | 4.715 | 4.598 | .469 | 4.508 | 4.801 | .484 | | 1399.50 | 1398.93 |
| 1600 | 5.357 | 5.307 | .531 | 5.317 | 5.346 | .547 | | 1602.53 | 1602.38 |
| 1800 | 5.986 | 6.013 | .594 | 6.047 | 5.948 | .609 | | 1803.15 | 1802.24 |
| 2000 | 6.620 | 6.706 | .656 | | | .656 | | 2002.57 | |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Himmelstein 2000 in lb Torque Shaft Calibration

PROJECT NO. 5056[illegible]

DATE 11-14-78

TECHNICIAN N.A.S.
J.O.M.

DESCRIPTION Daytronics 300D and Fluke VTVM for Load Cells.
Daytronics 3278 for Torque Shaft

INSTRUMENTATION
Daytronics Amplifiers
Fluke VTVM

COMMENTS
A - load cell 517 length 15.027 in
B - load cell 518 length 15.033 in
cal resistor value - 2016 IN LBS

Trial #5 Increasing Decreasing

| Target Torque IN LBS | A Force Volts | B Force Volts | Def. of Beam IN | A Force Volts | B Force Volts | Def. of Beam IN | | Calc. INC IN LBS | Torque DEC IN LBS |
|---|---|---|---|---|---|---|---|---|---|
| 0 | .015 | -.017 | 0 | .028 | -.020 | 0 | | 0 | 0 |
| 200 | .691 | .614 | .094 | .643 | .658 | .094 | | 196.56 | 195.51 |
| 400 | 1.361 | 1.280 | .156 | 1.288 | 1.351 | .172 | | 396.87 | 396.58 |
| 60[illegible] | 2.642 | 1.927 | .203 | 1.938 | 2.022 | .234 | | 597.18 | 595.09 |
| 800 | 2.600 | 2.708 | .281 | 2.634 | 2.678 | .313 | | 797.67 | 798.26 |
| [illegible] | 3.183 | 3.456 | .328 | 3.326 | 3.315 | .375 | | 997.69 | 999.48 |
| [illegible] | 3.[illegible]56 | 4.122 | .422 | 4.057 | 3.932 | .422 | | 1198.81 | 1200.59 |
| [illegible] | 4.[illegible] | 4.803 | .469 | 4.785 | 4.537 | .500 | | 1399.23 | 1400.85 |
| [illegible] | 5.155 | 5.502 | .531 | 5.511 | 5.151 | .563 | | 1601.50 | 1602.21 |
| [illegible] | [illegible] | 6.173 | .594 | 6.260 | [illegible] | .609 | | 1801.97 | 1803.87 |
| [illegible] | 6.463 | 6.873 | .656 | | | .656 | | 2004.09 | |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Himmelstein 2000 in lb Torque Shaft Calibration

PROJECT NO. 50560

DATE 5-10-79

TECHNICIAN N.A.S.

DESCRIPTION Absolute Value of Deviation from the Average

INSTRUMENTATION

COMMENTS

INC increasing value
DEC decreasing value

| Ave Value IN LBS | Trial #1 INC IN LBS | Trial #1 DEC IN LBS | Trial #2 INC IN LBS | Trial #2 DEC IN LBS | Trial #3 INC IN LBS | Trial #3 DEC IN LBS | Trial #4 INC IN LBS | Trial #4 DEC IN LBS | |
|---|---|---|---|---|---|---|---|---|---|
| 196.40 | .987 | .372 | 1.879 | 2.154 | .985 | .654 | 1.548 | 1.991 | |
| 395.52 | 1.485 | .452 | 1.790 | .771 | 1.622 | 1.787 | .928 | 2.205 | |
| 594.16 | .816 | 1.230 | 3.353 | 2.426 | 1.278 | 1.902 | 1.406 | 2.191 | |
| 793.58 | 1.200 | .937 | 2.817 | 2.547 | .039 | 1.423 | 2.281 | 1.916 | |
| 993.69 | .987 | 1.292 | 3.318 | 3.768 | 1.087 | 1.305 | 2.513 | 2.928 | |
| 1194.36 | 1.187 | 1.867 | 3.707 | 3.367 | .763 | 1.273 | 3.563 | 1.983 | |
| 1393.38 | 2.591 | .999 | 4.101 | 4.061 | 1.639 | .031 | 2.019 | 2.589 | |
| 1594.55 | 1.647 | 3.137 | 3.257 | 4.757 | 3.653 | 1.953 | 1.393 | 1.573 | |
| 1794.62 | 2.751 | 3.841 | 1.469 | 2.951 | 2.979 | 1.299 | 1.799 | 2.809 | |
| 1995.78 | 3.835 | 3.835 | 5.575 | 5.575 | 3.495 | 3.495 | 4.555 | 1.265 | |

| Ave Value IN LBS | Trial #5 INC IN LBS | Trial #5 DEC IN LBS | | |
|---|---|---|---|---|
| 196.40 | .868 | 1.380 | | |
| 395.52 | .457 | .746 | | |
| 594.16 | 1.084 | 2.52[illegible] | $\bar{x}$ = | 2.100 in-lbs |
| 793.58 | 1.216 | .706 | | |
| 993.69 | 1.644 | .141 | $\sigma$ | 1.326 in-lbs |
| 1194.36 | 1.263 | .983 | | |
| 1393.38 | 2.249 | .789 | $2\sigma$ | 2.651 in-lbs |
| 1594.55 | 2.323 | 1.963 | | |
| 1794.62 | 2.899 | 1.289 | | |
| 1995.78 | 3.005 | 3.005 | | |

Uncertainty of Himmelstein 2000 in-lb Torque Shaft

Laboratory Reference Uncertainty = 5.1 in-lbs

Readability Uncertainty = 1 in-lb

Calibration Uncertainty = $2\sigma$ = 2.651 in-lbs

Total Uncertainty = 5.1 + 1 + 2.65 = 8.75 in-lbs

## APPENDIX E

## TEMPERATURE CALIBRATION DATA

Uncertainty of Laboratory Reference Standard Thermometer #673650

Reference Calibration Error = 1°F

Readability Error

$$RE = \frac{2 \text{ x smallest scale div.}}{2 + RF_1}$$

$$RF_1 = 3(1-e^{(.5-1.1w)})$$

Smallest Scale Div. = 2°F

$$w = \frac{65 \text{ mm}}{50 \text{ div}} = 1.3$$

$$RF_1 = 3(1-e^{-.93}) = 1.82$$

$$RE = \frac{2 \text{ x } 2}{2 + 1.82} = \frac{4}{3.82} \quad 1.05°F$$

Total Uncertainty = 1 + 1.05 = 2.05°F

# FLUID POWER INSTITUTE
## MILWAUKEE SCHOOL OF ENGINEERING

TEST: Omega Iron - Constantan Thermocouple Calibration

PROJECT NO. 50560

DATE 10-19-78

TECHNICIAN J.O.M.
D.G.

DESCRIPTION Thermocouple #0

INSTRUMENTATION
DAS
Thermometer 673650

COMMENTS Calibrated with 10 ft. of extension lead

| Target Value °F | Trial #1 °F | Trial #2 °F | Trial #3 °F | Trial #4 °F | Trial #5 °F | Ave Value °F |
|---|---|---|---|---|---|---|
| 40 | 41.8 | 38.7 | 39.6 | 37.1 | 39.2 | 39.2 |
| 50 | 50.4 | 48.0 | 48.2 | 49.7 | 49.3 | 49.3 |
| 60 | 61.8 | 58.5 | 58.6 | 59.8 | 59.3 | 59.3 |
| 70 | 69.8 | 68.7 | 69.2 | 69.7 | 69.0 | 69.0 |
| 80 | 78.8 | 78.9 | 78.7 | 78.6 | 79.0 | 79.0 |
| 90 | 89.4 | 88.8 | 89.1 | 89.5 | 89.3 | 89.3 |
| 100 | 99.5 | 97.7 | 99.6 | 99.9 | 99.2 | 99.2 |
| 110 | 107.8 | 109.1 | 109.2 | 110.2 | 109.2 | 109.2 |
| 120 | 120.3 | 118.8 | 119.5 | 119.5 | 119.6 | 119.6 |
| 130 | 128.8 | 129.2 | 129.4 | 128.3 | 128.8 | 128.8 |
| 140 | 138.2 | 137.9 | 138.9 | 138.5 | 138.6 | 138.6 |
| 150 | 149.5 | 149.5 | 149.7 | 150.7 | 149.8 | 149.8 |
| 160 | 158.5 | 158.9 | 159.4 | 159.9 | 159.3 | 159.3 |
| 170 | 168.5 | 168.2 | 169.8 | 167.9 | 168.7 | 168.7 |
| 180 | 180.1 | 179.4 | 178.5 | 179.2 | 179.4 | 179.4 |
| 190 | 189.0 | 190.1 | 189.9 | 190.3 | 189.7 | 189.7 |
| 200 | 199.2 | 199.0 | 199.3 | 201.8 | 199.8 | 199.8 |
| 205 | - | 204.6 | 203.1 | 205.8 | 204.5 | 204.5 |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Omega Iron - Constantan
Thermocouple Calibration

PROJECT NO. 50560
DATE 10-19-78
TECHNICIAN J.O.M.
D.G.

DESCRIPTION
Thermocouple #0

INSTRUMENTATION

COMMENTS Absolute Value of Deviation From The Average

| Ave Value °F | | Trial #1 °F | Trial #2 °F | Trial #3 °F | Trial #4 °F | Trial #5 °F | | | |
|---|---|---|---|---|---|---|---|---|---|
| 39.2 | | 2.6 | .5 | .4 | .2 | 2.1 | | | |
| 49.3 | | 1.1 | 1.3 | 1.1 | .8 | .4 | | | |
| 59.3 | | 2.5 | 1.2 | 1.3 | 1.6 | .5 | | | |
| 69.6 | | .8 | .3 | .2 | 1.2 | .7 | | | |
| 79.0 | | .2 | .1 | .3 | 1.0 | 1.6 | | | |
| 89.3 | | .1 | .5 | .2 | .4 | .2 | | | |
| 99.2 | | .3 | 1.5 | .4 | .3 | .7 | | | |
| [illegible] | | 1.4 | .1 | 0 | .6 | 1.0 | | | |
| 119.6 | | .7 | 1.2 | .1 | .1 | .1 | | | |
| 126.8 | | 0 | .4 | .6 | .5 | .5 | | | |
| 136.6 | | .4 | 1.3 | .3 | .7 | .1 | | | |
| 149.8 | | .3 | .3 | .1 | .2 | .9 | | | |
| 159.3 | | .8 | .4 | .1 | .5 | .6 | | | |
| 166.7 | | .2 | .5 | 1.1 | .2 | .8 | | | |
| 179.4 | | .7 | 0 | .9 | .5 | .2 | | | |
| [illegible] | | .7 | .4 | .2 | .6 | .6 | | | |
| [illegible] | | .6 | .8 | .5 | .1 | 2.0 | | | |
| [illegible] | | - | .1 | 1.4 | .2 | 1.3 | | | |
| | | | | | | | | | |
| | | | σ | .866 °F | | | | | |
| | | | 2σ | 1.732 °F | | | | | |

Uncertainty of Working Instrument Thermocouple #0

Reference Standard Error = 2.05°F

Calibration Error $2\sigma$ = 1.732°F

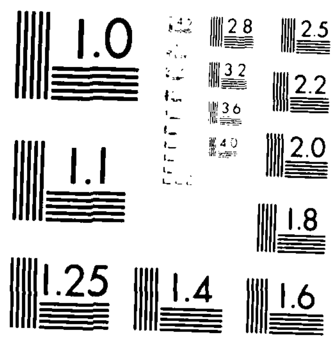
Readability Error = .1°F

Total Uncertainty = 2.05 + 1.732 + .1 = 3.88°F

AD-A152 248 INVESTIGATION INTO HYDRAULIC GEAR PUMP EFFICIENCIES DURING THE FIRST FEW..(U) MILWAUKEE SCHOOL OF ENGINEERING WI FLUID POWER INST 12 NOV 79 3/3

UNCLASSIFIED P/N-50560-PTS-1/2 DAAK70-77-C-0214 F/G 13/11 NL

END




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST: Omega Iron - Constantan
Thermocouple Calibration

PROJECT NO. 50560
DATE: 10-19-78
TECHNICIAN: J.O.M.
D.G.

DESCRIPTION
Thermocouple #1

COMMENTS: Calibrated with 10 ft. extension lead

INSTRUMENTATION
DAS
Thermometer 673650

| Target Value °F | | Trial #1 °F | Trial #2 °F | Trial #3 °F | Trial #4 °F | Trial #5 °F | | Ave. Value °F | |
|---|---|---|---|---|---|---|---|---|---|
| 40 | | 41.1 | 38.8 | 39.2 | 38.7 | 38.1 | | 39.2 | |
| 50 | | 49.6 | 47.8 | 47.6 | 49.9 | 50.5 | | 49.1 | |
| 60 | | 62.4 | 59.1 | 58.3 | 57.3 | 58.5 | | 59.1 | |
| 70 | | 69.3 | 68.3 | 69.0 | 68.6 | 68.1 | | 68.7 | |
| 80 | | 79.4 | 78.6 | 79.0 | 79.8 | 78.6 | | 79.1 | |
| 90 | | 90.4 | 88.8 | 88.2 | 90.1 | 87.7 | | 89.0 | |
| 100 | | 98.8 | 98.3 | 99.2 | 98.1 | 97.4 | | 98.4 | |
| 110 | | 108.6 | 109.3 | 109.1 | 109.7 | 107.8 | | 108.9 | |
| 120 | | 119.6 | 118.3 | 118.6 | 120.6 | 117.7 | | 119 | |
| 130 | | 128.9 | 129.1 | 128.4 | 130.1 | 129.1 | | 129.2 | |
| 140 | | 138.6 | 138.4 | 138.3 | 140.1 | 140.5 | | 139.2 | |
| 150 | | 149.6 | 148.8 | 147.8 | 150.8 | 148.8 | | 149.2 | |
| 160 | | 159.8 | 158.2 | 159.8 | 161.1 | 158.7 | | 159.5 | |
| 170 | | 168.9 | 169.2 | 169.1 | 169.2 | 170 | | 169.3 | |
| 180 | | 179.3 | 179.2 | 179.9 | 179.0 | 177.3 | | 178.9 | |
| 190 | | 189.7 | 189.1 | 189.2 | 189.2 | 189.8 | | 189.4 | |
| 200 | | 199.2 | 198.5 | 200.9 | 200.5 | 200.2 | | 199.9 | |
| [illegible] | | 205.5 | 205.7 | 204.3 | 204.3 | 205,3 | | 205 | |

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST Omega Iron - Constantan
Thermocouple Calibration

PROJECT NO. 50560
DATE 10-19-78
TECHNICIAN J.O.M.
D.G.

DESCRIPTION
Thermocouple #1

INSTRUMENTATION

COMMENTS Absolute Value of Deviation from the Average

| Ave Value F | | Trial #1 °F | Trial #2 °F | Trial #3 °F | Trial #4 °F | Trial #5 °F |
|---|---|---|---|---|---|---|
| 39.2 | | 1.9 | .4 | 0 | .5 | 1.1 |
| 49.1 | | .5 | 1.3 | 1.9 | .8 | 1.4 |
| 59.1 | | 3.3 | 0 | .8 | 1.8 | .6 |
| 68.7 | | .6 | .4 | .3 | .1 | .6 |
| 79.1 | | .3 | .5 | .1 | .7 | .5 |
| 89.0 | | 1.4 | .2 | .8 | 1.1 | 2.3 |
| 98.4 | | .4 | .1 | .8 | .3 | 1.0 |
| 108.9 | | .3 | .4 | .2 | .8 | 1.1 |
| 119.6 | | .6 | .7 | .4 | 1.6 | 1.3 |
| 129.2 | | .2 | 0 | .5 | 1.0 | 0 |
| 139.2 | | .6 | .8 | .8 | .9 | .7 |
| 149.2 | | .4 | .4 | .4 | 1.6 | .4 |
| 159.5 | | .3 | 1.3 | 1.3 | 1.6 | .8 |
| 169.3 | | .6 | .1 | .1 | .1 | .7 |
| 178.9 | | .4 | .3 | .3 | .1 | 1.6 |
| 189.4 | | .3 | .3 | .3 | .2 | .4 |
| 199.9 | | .7 | 1.4 | 1.4 | .6 | .3 |
| 205 | | .5 | .7 | .7 | .7 | .3 |
| | | | σ | .924 °F | | |
| | | | 2σ | 1.848 °F | | |

Uncertainty of Working Instrument Thermocouple #1

Reference Standard Error = 2.05°F

Calibration Error = $2\delta$ = 1.848°F

Readability Error = .1°F

Total Uncertainty = 2.05 + 1.848 + .1 = 4.00°F

## APPENDIX F

## BREAK-IN SURVEY RESULTS

Surveys Mailed = 32  Received = 13  Declined = 7



No Response = 12

PUMP BREAK-IN PROCEDURE SURVEY

MSOE FLUID POWER INSTITUTE

* Complete and return by 16 Dec., 1977 *

Instructions:

Please circle the appropriate response to the following questions and/or fill in the required information. Additional data is requested in the attached chart.

1.0 Break-In Procedure General  NA = no answer

1.1 Do you have a criterion for determining the point at which a pump is satisfactorily broken in?

Yes 8  No 4  NA 1

1.2 Is your procedure based on developmental or laboratory studies?

Yes 9  No 3  NA 1

1.3 Has your procedure evolved over time and experience with product?

Yes 10  No 2  NA 1

1.4 Was your procedure arbitrarily arrived at?

Yes 4  No 8  NA 1

1.5 Are identical procedures used in production prior to product shipment and in the service department?

Yes 12  No  NA 1

1.6 Do your engineering department recommendations or laboratory test procedures differ from 1.5 above?

Yes 1  No 11  NA 1

2.0 Break-In Procedure Specifications

2.1 Do you conduct your pump break-in at:

Constant pressure  Yes 2  No 10  NA 1

Constant speed  Yes 10  No 2  Yes + No 1

Constant torque  Yes  No 12  NA 1

2.2 Do you have contamination sensitivity test results on your pumps?

Yes 5  No 7  NA 1

2.3 Do you have different break-in procedures for different gear pump design features such as bearing types, bearing mounts, shaft seal types, and pressure loaded wear plates?

Yes 3  No 9  NA 1

If yes, how many different break-in procedures do you use?

6, 3, 2

GEAR PUMP BREAK-IN PROCEDURE

2.4 (Fill out each different break-in procedure you recommend to prepare a sample gear pump for one-time qualification test.)

Product Description:

Special Fluid:

Contamination:

Additives (Lubricity):

Additives (Abrasion):

Water Content Limit:

Procedure (Describe each different gear pump break-in procedure you use and state the important design features which set this one apart from the others- Be sure to include information regarding range of variable conditions, ie. speed, pressure, torque, on and off time, and total elapsed time of procedure. Use extra pages if needed.)

For a summary of the responses to this section of the questionnaire, see section 2.2.2 page 84.

3.0 Are you willing to submit to MSOE an oil sample from your break in test stand for contamination particle counting and water content in exchange for the fluid an lysis results at no charge to you?

Yes 8 No 5

(If you check yes, we will send you a clean bottle.)

4.0 The research program consists primarily of testing the overall efficiency of 18 hydraulic gear pumps during the first few hours of the pump's lives, that is, during the break-in period. A uniform break-in procedure will be devised based upon the results of this survey. Later, selected manufacturers will be asked to contribute six pumps each for the test program.

Are you willing to participate in this test program by contributing 6 identical standard production gear pumps in exchange for confidential test results at no charge? The data generated and reported will be coded to maintain confidentiality. The Army will receive only statistical summaries. You will, however be credited for participating in the program.

Yes 9 No 4

MSOE FLUID POWER INSTITUTE
PUMP BREAK-IN PROCEDURE SURVEY

5.0 External Gear Pump Design Features

| | |
|---|---|
| Needle Bearings | 3 |
| Roller Bearings | 4 |
| Hydrodynamic Plain Bearings | 9 |
| T.F.E. Plain Bearings Steel Backed | 3 |
| T.F.E. Plain Bearings Filament Wound | 0 |
| Resilient Shaft Seal | 10 |
| Mechanical Shaft Seal | 4 |
| Press Fit Bearing Mount | 6 |
| Self Aligning Bearing Mount | 0 |
| Pressure Loaded Wear Plates | 6 |

# APPENDIX G

## NFPAT3.9.17R1 CALIBRATION ANNEXES

# ANNEX A

## A GLOSSARY OF TERMS IN SUPPORT OF TESTING IN A HYDRAULIC FLUID POWER LABORATORY

1.0 Purpose:

To set forth those terms and their definitions needed to understand the technology associated with accurate measurement of the physical variables encountered in the assessment of fluid power equipment.

2.0 Scope:

2.1 Includes terms used for understanding calibration of instruments.

2.2 Includes terms used for understanding measurement of physical variables in fluid power systems.

3. References:

4.0 TERMS AND DEFINITIONS

4.1 Agency: Any person or organization or part, section, department or division of an organization which maintains equipment and supporting records for the purpose of engaging in any or all of the following:

A. Calibration of Reference Standards
B. Calibration of Working Instruments
C. Testing of Fluid Power Equipment

4.2 Calibration: The process of comparing a first Reference Standard to a second Reference Standard or Working Instrument Reference Standard or Working Instrument.

4.3 Calibration Situation: That time when a Working Instrument is Calibrated against a Reference Standard.

4.4 Certificate: A written statement by a Certified Calibration Agency that a calibration has been carried out in accordance with this standard.

4.5 Certified Calibration: The process of comparing a Certified Reference Standard to another Reference Standard or Working Instrument and providing supporting documentation in accordance with this standard.

4.6 Certified Calibration Agency: Any Agency which maintains Reference Standards and supporting documentation in accordance with this standard.

4.7 Certification Lineage: That path which traces the calibration of an instrument to the Ultimate Reference Standard.

4.8 Dummy Calibration: A process whereby a signal to a transducer is simulated electronically in order to facilitate the return of electronic gains to the levels used during Calibration. Use of Dummy Calibration is not a substitute for Verification or Calibration.

4.9 Environmental Factors: Any physical variable other than the measurand which affects the output of an Instrument. In a pressure transducer, for instance, temperature may cause a span or zero shift, making temperature an Environmental Factor affecting the pressure measurement. In another case, pressure may affect a temperature transducer, making pressure the Environmental Factor.

[illegible] Error: The estimated uncertainty surrounding a given measurement which establishes the boundaries [illegible] which the true value lies relative to the Indicated Value.

[illegible] Error Contribution: An estimate of that amount of uncertainty which contributes to the Total Error and is attributable to a single error producing phenomenon.

[illegible] Indicated Value: The [illegible] of a value based upon the [illegible] Reading

[illegible]

3.1.1.4 Calculate the Readability Error for the Readout Device with the Formula:

$$RE = \frac{\text{Value of the Smallest Scale Division}}{[RF_1 \times RF_2 + 2.0]}$$

3.1.2 The overall Readability Factor for a Readout Device having a moving column, such as is the case with a liquid manometer, shall be calculated using:

$$RE = \frac{\text{2x Value of the Smallest Scale Division}}{RF_1 + 2.0}$$

Where $RF_1$ is determined as in clause 3.1.1.2

3.2 Digital Readout Devices

3.2.1 The Readability Error shall be calculated using the formula:

RE = Smallest Change in the Least Significant Digit

3.2.1.1 Take into account the fact that by design, the least significant digit in some Digital Readout Devices does not have 10 discreet integer levels. Use the value of the smallest integer change possible for the particular readout.

4.0 Readout Device Labels

4.1 Enter the overall Readability Error, as determined in clause 3.1.1.3, 3.1.2 or clause 3.1.1, into the Readout Device's Label.

# ANNEX D

## RECOMMEND PROCEDURE FOR EVALUATING READABILITY ERROR OF READOUT DEVICES USED IN FLUID POWER TESTING

1.0 Purpose: To set forth the procedure for determining the amount of error contributed because of the inability to assign an unlimited number of digits to the indicated value of a measured quantity.

2.0 Scope:

2.1 Includes both analog and digital Readout Devices.

3.0 Evaluation of Readability Error Factor.

3.1 Analog Readout Devices

3.1.1 The Readability Error (RE) for a Readout Device equipped with a pointer shall be calculated using:

$$RE = \frac{\text{Value of the Smallest Scale Division}}{[RF_1 \times RF_2 + 2.0]}$$

Where $RF_1$ and $RF_2$ are determined from properties of the Readout Device as follows:

3.1.1.1 The Readout Device shall be equipped with a parallax error minimizing feature.

3.1.1.2 Determine within 10%, the width of the smallest scale division in mm (W)

Calculate $RF_1$ with the formula:

$RF_1 = 3(1 - \varepsilon^{0.5 - 1.1W})$ $\quad W \geq 0.5$ mm

$RF_1 = 0.0$ $\quad W < 0.5$ mm

3.1.1.3 Estimate the width of the pointer to the nearest 0.25 mm in the region on the pointer where the reading is interpreted. Divide the width of the smallest scale division found in 3.1.2.2 by the pointer width to form the ratio, $\alpha$.

Calculate $RF_2$ with the formula:

$RF_2 = 1 - \varepsilon^{0.6(1-\alpha)}$ $\quad \alpha \geq 1.0$

$RF_2 = 0$ $\quad \alpha < 1.0$

8.3 Evaluate the coefficients in the Mathematical Model using least squares fitting methods applied to all data taken from calibration in accordance with Annex C.

8.4 Calculate the difference between the Indicated Value and the value predicted by the derived mathematical model of all trials at each Reference Value by:

Indicated Value - Predicted Value

8.5 Calculate the standard deviation of all values found in 8.4 over the total range of Reference Values.

8.6 Multiply the standard deviation by two for a confidence level of 95%. Enter this as the Calibration Error on the Working Instrument's label.

8.7 Implement the Mathematical Model by substituting the Indicated Values and values of the Environmental Factors measured during the Measurement Situation into the formula. That result is the estimate of the actual value at measurement time. Its Calibration Error is the amount recorded in clause 8.6.

Note: If the average Indicated Value deviates from its corresponding Reference Value by 1% or less, the Reference value may be substituted for the average Indicated Value with minimal adverse effect.

7.2.5.1 In the Measurement Situation, enter each Indicated Value into the ordinate and read the best estimate of the actual value from the abscissa.

7.2.5.2 Assume linear interpolation between discreet data entries.

7.2.5.3 Take Environmental Factors into account by:

A. An alternate mathematical model which included their effects.

B. Using instruments which have insignificant influence by Environmental Factors.

C. Controlling Environmental Factors during the Measurement Situation to be insignificant agreement with their values during calibration.

8.0 Fourth Order Mathematical Model:

8.1 A Fourth Order Mathematical Model accomodates complex mathematical functions which relate the actual value to the Indicated Value and any influencing Environmental Factors. It has no specific general form.

8.2 Determine the general form of the mathematical relationship using any one or combination of the following means:

8.2.1 Use accepted theories.

8.2.2 Use empirical data as determined during controlled experiments on the instrument.

8.2.3 Use manufacturer's data, such as, for instance, zero shift due to temperature, or span shift due to viscosity, etc.

8.2.4 Ignore Environmental Factors when they are brought into sufficient agreement in the Measurement Situation with the values that existed during the Calibration Situation.

8.2.5 Ignore Environmental Factors which are known to have an insignificant influence upon the Indicated Value.

6.3 Evaluate $b_0$, $b_k$ and $a_i$ using linear regression on all data from all trials of calibration as conducted in Annex C.

6.4 Calculate the difference between the Indicated Value and the value predicted by the derived mathematical model of all trials at each Reference Value by:

Indicated Value - Predicted Value

6.5 Calculate the standard deviation of all values found in 6.4 over the total range of Reference Values.

6.6 Multiply the standard deviation by two for a confidence level of 95%. Enter this as the Calibration Error on the Working Instrument's label.

6.7 Implement the Mathematical Model by substituting the Indicated Values and values of the Environmental Factors measured during the Measurement Situation into the formula. That result is the estimate of the actual value at measurement time. Its Calibration Error is the amount recorded in clause 6.6.

7.0 Third Order Mathematical Model:

7.1 A Third Order Mathematical Model makes use of a point-to-point correction under the assumption that corrections are linear when Indicated Values taken in the Measurement Situation lie between data points used during the Calibration Situation.

7.2 Evaluate the Calibration Error

7.2.1 For each Reference Value: Calculate the average Indicated Value of all the trials at each Reference Value.

7.2.2 Calculate the difference between the indicated value and the average indicated Value of all the trials at each Reference value by: Indicated Value - Average Indicated Value.

7.2.3 Calculate the standard deviation of all values found in 7.2.2 over the total range of Reference values.

7.2.4 Multiply the standard deviation by two for a confidence level of 95%. Enter this as the calibration error on the working instrument's label.

7.2.5 Implement the Mathematical Model by constructing a graph of the average Indicated Values found in clause 7.2.1 (as averaged over all the trials for each Referenced Value) vs. the Reference Values.

5.2 Evaluate the Calibration Error

5.2.1 Use the Calibration data as recorded using Annex B.

5.2.2 Calculate the difference between the Indicated Value and the Reference Value of the five trials at each Reference Value by: Indicated Value - Reference Value.

5.2.3 Calculate the standard deviation of all values found in 5.2.2 over the total range of Reference Values.

5.2.4 Multiply the standard deviation by two for a confidence level of 95%. Enter this as the Calibration Error on the Working Instrument's label.

5.2.5 Implement the Model by using as indicated on the Readout Device.

6.0 Second Order Mathematical Model:

6.1 A Second Order Mathematical Model assumes that the Indicated Value is related to the actual value of a physical variable and any influencing Environmental Factors through a formula of the form:

$$\text{Actual Value} = b_o + \sum_{k=i}^{m} b_k \times (\text{Indicated Value})^k + \sum_{i=1}^{n} a_i f(E_i)$$

where $E_i$ is one of $n$ influencing Environmental Factors, $f(E_i)$ is the functional manner in which $E_i$ affects the measurement of the actual value and $a_i$ is a linear coefficient which affects the degree of effect.

6.2 Determine $f(E_i)$ by any one or combination of the following methods:

6.2.1 Use acceptable theories.

6.2.2 Use empirical data as measured during controlled experiments during Working Instrument Calibration.

6.2.3 Use manufacturer's data, such as, for instance, zero shift due to temperature, or span shift due to viscosity, etc.

6.2.4 Ignore Environmental Factors when they are brought into sufficient agreement in the Measurement Situation with the values that existed during the Calibration Situation.

6.2.5 Ignore Environmental Factors which are known to have an insignificant influence upon the Indicated Value.

# ANNEX C

## RECOMMENDED METHOD FOR DETERMINING AN INSTRUMENT'S CALIBRATION ERROR THROUGH DEVELOPMENT OF A SUITABLE MATHEMATICAL MODEL

1.0 Purpose:

1.1 To set forth the procedures for driving mathematical models of a Working Instrument and, when applicable, to evaluate effects of Environmental Factors.

1.2 To determine the Calibration Error of a Working Instrument.

1.3 To set forth procedures which can be used to bring an instrument's Calibration Error to approach its limit of non-repeatability.

1.4 To determine the value of Calibration Error to be entered on the Instrument's Label.

2.0 Scope:

2.1 To include four different models.

2.2 To include methods of dealing with Environmental Factors.

3.0 Definitions:

3.1 Refer to Annex A.

3.2 All terms used in this Standard which are capitalized are defined in Annex A.

4.0 General Procedures:

4.1 Select a suitable Mathematical Model from one of the four in clauses 5.0, 6.0, 7.0, or 8.0 (Note: The amount of Calibration Error in most Instruments will depend upon the Model Selected. Higher order Models will yield smaller errors).

4.2 Evaluate the Model in accordance with the applicable clauses.

4.3 Enter the Calibration Error, as evaluated in the applicable clause, on the Instrument's Label.

5.0 First Order Mathematical Model:

5.1 A First Order Mathematical Model makes direct use of the Indicated Value of a Readout Device without resorting to any corrections. The Instrument and Readout Device are [illegible]

# TABLE 2

## FREQUENCY OF CALIBRATION - WORKING INSTRUMENTS

| Variable/Type of Working Instrument | Frequency of Calibration |
|---|---|
| **TORQUE:** | |
| Strain Gage | 24 Months |
| Calibrated Motor | 12 Months |
| Cradled Dynometer | 10 Months |
| **PRESSURE:** | |
| All Types | 12 Months |
| **FLOW:** | |
| All Types | 12 Months |
| **SPEED:** | |
| Mechanical Tachometers | 6 Months |
| DC Electrical Generaters | 6 Months |
| Electronical Digital Frequency Meters | 2 Months |
| Other Types | 6 Months |
| **TEMPERATURE:** | |
| All Types | 12 Months |
| **FORCE:** | |
| Dead Weights | 10 Years |
| Balance Scales | 6 Months |
| Load Cells | 6 Months |
| Other Types | 6 Months |
| **DISTANCE:** | |
| Gage Blocks | 2 Years |
| Tapes | 5 Years |
| Micrometers | 2 Months |
| **TIME:** | |
| All Types | 2 Months |

TABLE 1

Draft #2
14 April, 1978

FREQUENCY OF CALIBRATION - REFERENCE STANDARDS

| Variable/Type of Standard | Frequency of Calibration |
|---|---|
| TORQUE: | |
| Strain Gage | Every four years |
| Force and Distance | Every five years |
| PRESSURE: | |
| Master Guages | Every two years |
| Dead Weight Testers | Every ten years |
| Strain Gage | Every two years |
| Other Transducers | Every two years |
| Liquid Manometers | Liquid properties every five years height every 10 years |
| FLOW: | |
| Positive Displacement Reference Meters | Every five years |
| Turbine Reference Meters | Every two years |
| Volume and Time Provers | Every ten years |
| Weight and Time Provers | Every ten years |
| SPEED: | |
| Electronic Digital Frequency Meters | Every year |
| Stroboscopes | Each use |
| Reference Tachometer | Every two years |
| TEMPERATURE: | |
| Mercury in Glass | Every five years |
| Thermocouple | Every year |
| Bimetal | Each Use |
| Gas Filled | Each Use |
| FORCE: | |
| Dead Weights | Every ten years |
| Load Cells | Every two years |
| Balance Scales | Every year |
| DISTANCE: | |
| Guage Blocks | Every ten years |
| Tapes | Every ten years |
| Micrometers | Every two years |
| TIME: | |
| Electronic Digital Timers | Every year |
| Chronometers, Mechanical | Every six months |
| Chronometers, Electro-Mechanical | Every year |

7.1.5 Working Instrument Identification

7.1.6 Identification of the person responsible for the Calibration of the Working Instrument.

7.2 Enter the date of the next required calibration on the Label in the appropriate place.

7.3 Enter the Total Error of the Reference Standard on the Label in the appropriate place.

7.3.1 If the Total Error is stated in terms of the Maximum or full-scale value, use that value.

7.3.2 If the Total Error is stated in terms of the Indicated Value (Reading), use a value determined from that and the full-scale value of the Working Instrument being calibrated.

7.4 Affix the Label to the Instrument's Readout Device in a manner which will discourage its inadvertent removal and yet will not interfere with reading.

8.0 Propose a Mathematical Model of the Working Instrument in accordance with Annex C & D.

6.1.3 Collect calibration data.

6.1.3.1 Couple the Working Instrument to the Reference Standard.

6.1.3.2 For Working Instruments which are subject to hysteresis effects due to, for instance, material characteristics or static friction, carry out the calibration for both increasing and decreasing Reference Values.

6.1.3.3 Take advantage of any correction charts or mathematical models which may have resulted from Calibration of the Reference Standard which are needed to confine the Reference Standard's Total Error to the Certified amount.

6.1.3.4 Make corrections to the Reference Values for any other Systematic Errors when the relationships with other physical variables are known and the physical variables themselves are known (measured) at the time of Working Instrument Calibration and if the effects of the Systematic Errors will otherwise be significant.

6.1.3.5 Record data:

A. Reference value, after any corrections as may be applicable from the two previous clauses.

B. Indicated Value from the Working Instrument.

6.1.3.6 Repeat 6.1.3.5 for at least five trials and use at least 10 calibration points for each. Use the same set of Reference values during each trial.

6.1.3.7 Make note of anything unusual about the physical appearance of the instrument.

6.1.3.8 Sign the calibration data sheets and place them into a safe, permanent file. This record is the Working Instrument's Certificate.

7.0 Instrument Label

7.1 Prepare a Label for the Instrument which will identify and have room for the following data:

7.1.1 Date of the next scheduled Calibration as required in Table 2 of this Annex in order to remain in Certification.

7.1.2 Total Error of the Reference Standard used in Calibrating the Working Instrument.

7.1.3 Calibration Error of the Working Instrument as determined after development of a Mathematical Model in accordance with Annex D.

7.1.4 Readability Error as determined in accordance with Annex E.

# ANNEX B

## RECOMMENDED METHOD FOR CALIBRATING WORKING INSTRUMENTS FOR USE IN TESTING FLUID POWER EQUIPMENT

1.0 Purpose: To set forth the calibration procedures of Working Instruments used in fluid power measurements.

2.0 Scope:

2.1 To include requirements of Reference Standards.

2.2 To include requirements of Working Instruments.

2.3 To include procedures for calibrating Working Instruments.

2.4 To include the requirements of the Working Instrument's Label.

3.0 Definitions:

3.1 Refer to Annex A

3.2 All terms used in this standard which are capitalized are defined in Annex A.

4.0 General Procedures

4.1 Select a Reference Standard per clause 5.0.

4.2 Calibrate the Working Instrument per clause 6.0.

4.3 Prepare an Instrument Label per clause 7.0.

5.0 Select a Reference Standard:

5.1 Which is certified to have been, itself, traceably calibrated within the intervals given in Table 1.

5.2 Which is free of physical damage except as noted on its certificate.

5.3 Which has had its total error evaluated and certified.

5.4 Mount the Reference Standard in an attitude indicated on its Certificate, or in that attitude recommended by its manufacturer.

6.0 Calibrate the Working Instrument at the applicable frequency given in Table 2.

6.1 Select a Working Instrument which is free from physical damage.

6.1.1 Mount the Working Instrument in an attitude recommended by the manufacturer or in an attitude expected in the Measurement situation.

6.1.2 Make zero value checks with the Working Instrument physically uncoupled from any possible loading effects.

4.29 Snubber: A hydraulic restriction deliberately placed between the source of pressure to be measured and the pressure transducer for the purpose of damping pressure pulsations.

4.30 Static Pressure: That pressure in a line which does not include effects due to fluid momentum.

4.31 Steady-State: An operating condition in a hydraulic system which is characterized by the fact that

$$\int_{\tau_1}^{\tau_1 + 2\pi k} p(t)\,dt = \int_{\tau_2}^{\tau_2 + 2\pi k} p(t)\,dt$$

and where $\tau_1$ and $\tau_2$ are arbitrary and k is an integermultiple of the period of the fundamental frequency of the pulsation.

4.32 Symmetry Test: A test conducted on a Snubber for the purpose of determining the extent to which its reverse pressure-flow characteristic agrees with its forward pressure-flow characteristic for the further purpose of assessing its Error Contribution. See Section 9 for details.

4.33 Systematic Error: A repeatable error which is caused by a physical phenomenon which, if sufficient experimental evidence exists, can be eliminated.

4.34 Testing Agency: Any Agency which conducts tests on Fluid Power Equipment.

4.35 Total Error: The total estimated uncertainty in the value of a measured quantity caused by the combined effect of all Error Contributing phenomena.

4.36 Verification, Working Instrument: An abbreviated calibration procedure carried out at specified intervals between Certified Calibrations.

4.37 Working Instrument: A measuring system, which includes interconnecting linkages, any necessary signal conditioning and signal processing and the readout device, which is used by the Testing Agency while conducting tests on Fluid Power Equipment.

4.14 Mathematical Model: A graph, chart or equation which relates the indicated Value to the value of the measurand.

4.15 Measurement Situation: That time when a Testing Agency incorporates Working Instruments in the testing of fluid power components and/or systems.

4.16 Physical Standards Laboratory: That agency which is recognized by a national government as capable of maintaining Ultimate Reference Standards.

4.17 Pressure Measurement System: All those devices which are interconnected between the system, the pressure of which is to me measured, and the final readout device.

4.18 Pressure Transducer: Any device which senses fluid pressure and converts it to an electrical signal.

4.19 Random Error: An error which has no known physical cause and is completely unpredictable except within some bounds.

4.20 Readability: A generic term used to describe the ability of a human observer to assign a digital quantity to the value displayed on a Readout Device.

4.21 Readability Error: The error caused by the inability to assign an unlimited number of digits to the output of an instrument.

4.22 Readout Device: That mechanism which ultimately displays the value of a physical variable within a system in a form upon which logical decisions can be made.

4.23 Reference Standard: A measuring system which is used only to calibrate other measuring devices and/or systems.

4.24 Reference Standard, Intermediate: A Reference Standard maintained by any person or organization other than the Physical Standards Laboratory and which has been certified in accordance with this standard.

4.25 Reference Standard, Laboratory: A Reference Standard which is permitted between the Ultimate and/or Intermediate References in certain special cases, criteria for which are contained in this standard.

4.26 Reference Standard, Ultimate: That Reference Standard maintained by the Physical Standards Laboratory. The most authoritative Reference Standard in a given country.

4.27 Reference Value: The best estimate of the actual value of a physical variable experienced by an instrument during its calibration, taking into account corrections in fluid column height and calibration corrections for the Reference Standard. It should not be confused with the true value which can never be known exactly.

4.28 Second Order Error: The error induced in the determination of a measured quantity caused by a measurement error in an Environmental Factor which is going to be used to make a correction to the basic measured quantity.

APPENDIX H.

NFPA T3.9.17R1 Draft #5

Method of Testing and Presenting Basic Performance Data for Positive Displacement Hydraulic Fluid Power Pumps

# Method of Testing and Presenting Basic Performance Data for Positive Displacement Hydraulic Fluid Power Pumps

T3.9.17R1

DRAFT #5

20 MARCH, 1980

Sponsor
National Fluid Power Association, Inc

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## REFERENCES

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2. International Standard Graphical Symbols for Hydraulic and Pneumatic Equipment and Accessories for Fluid Power Transmission, ISO/R 1219-1970. Agrees with ANSI/Y32.10-1967.
3. American National Standard Fluid Power Diagrams, ANSI/Y14.17-1966.
4. American National Standard Graphic Symbols for Fluid Power Diagrams, ANSI/Y32.10-1967. (ISO/R 1219-1970.)
5. International Standard Rules for the Use of Units of the International System of Units and a Selection of the Decimal Multiples and Sub-Multiples of SI Units, ISO/R 1000-1973.
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7. American Society for Testing and Materials Standard Method for Calculating Viscosity Index from Kinematic Viscosity, ASTM/D2270-1968.
8. American Society for Testing and Materials Standard Method of Test for Viscosity of Transparent and Opaque Liquids, ASTM/D445-1965.
9. National Fluid Power Association Recommended Standard Filtration for Hydraulic Fluid Power Systems, NFPA [illegible]

T3.9.17R1
Draft #5
20 March, 1980

# FOREWORD

(This Foreword is not part of American [illegible] Method of Testing and Presenting Basic Performance D[illegible] Positive Displacement Hydraulic Fluid Power Pumps and Motors, ANSI/B93.27-1973.)

In 1964, producers and users of hydraulic fluid power pumps [illegible] expressed the need for more meaningful, consistent and accurate means for determining and expressing component performance capabilities. The only existing standards were limited in scope to components used only on mobile equipment. Upon request to the NFPA Technical Board, projects were authorized and assigned to the NFPA Pump and Motor Section.

At the outset, work was divided into two parts: "Methods of Test" and "Methods of Rating". Drafting of the interrelated documents progressed at a somewhat parallel pace. Drafting was completed in late 1967. The separate documents were simultaneously submitted to general industry review. Separate review and modification proceeded until 1970, when it was agreed that the documents should be [illegible] combined. To facilitate international acceptance, the Secretary was also directed to incorporate, wherever possible, material resulting from International Standardization actions. Also, the basic research at Oklahoma State University and the standards actions of the Society of Automotive Engineers and the British Standards Institute were to be taken into account.

The combined and revised draft was completed on 23 November 1970. It was circulated for comments and improved during the 15 December meeting. Balloting was undertaken on 18 December 1970.

The ballot, which closed on 15 January 1971, was concluded successfully thru editorial clarifications. One clarification [illegible] noteworthy: the original test for structural integrity called for a test at 1[illegible] percent of manufacturer's maximum rated output pressure, it is now 115 percent of MAOP (maximum allowable operating pressure).

On 20 January 1971, the Technical Board judged that all negative ballots and comments had been resolved [illegible] and recommended approval. Approval as an NFPA Recommended Standard was granted by the Board of Directors on 21 January 1971. Editorial action was completed on 31 August 1971.

Members of the NFPA Project Group that prepared this standard are listed on page 4.

On 30 December 1971, the NFPA Recommended Standard was submitted to ANSI Standards Committee B93 for promulgation as an ANSI Standard. Favorable ballot was concluded on 28 February 1972. Approval by the ANSI Board of Standards Review was granted on 7 March 197[illegible].

The membership roster for Standards Committee B93 at the time of approval is listed on page [illegible].

Members of the NFPA Project Group that develope[illegible] included

| | | |
|---|---|---|
| Christensen, Norm | Project Co-Chairman | [illegible] Inc. |
| Graham, MacKellar | Project Co-Chairman | [illegible] Vickers |
| Olson, John | Section Chairman | Applied Power |
| Czarnecki, George | Section Vice Chairman | [illegible] Turbine Inc. |
| Mills, A. D. | Section Secretary | Continental Hydraulics |
| Morgan, James I. | Secretariat | National Fluid Power Assn. |

| | |
|---|---|
| Chenoweth, R. | Denison Division |
| Englander, R. | Tyrone Hydraulics |
| Freeze, G. | Cessna Aircraft Co. |
| Funk, C. | Eaton Corp. |
| Kay, R. | Sperry Vickers |
| Olen, R. | HUSCO |
| Ratkay, E. | Commercial Shearing |
| Sanders, M. | Tyrone Hydraulics |
| Schwary, R. | Hydreco |

On 28 February 1972 Standards Committee B93 was comprised of the following:

John J. Pippenger, Chairman; Otto J. Maha, Vice Chairman; James I. Morgan, Co-Secretary; J. C. Crawford, Co-Secretary.

AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS
E. H. Fletcher

AMERICAN SOCIETY OF LUBRICATION ENGINEERS
Howard Kaufman

AMERICAN SOCIETY OF MECHANICAL ENGINEERS
Henry Parsons
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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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AUTOMOBILE MANUFACTURERS ASSOCIATION
Reino Mustonen

CONSTRUCTION INDUSTRY MANUFACTURERS ASSOCIATION
Glenn Stewart
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T3.9.17R1
Draft #5
20 March, 1980

# METHOD OF TESTING AND PRESENTING BASIC PERFORMANCE DATA FOR POSITIVE DISPLACEMENT HYDRAULIC FLUID POWER PUMPS

## INTRODUCTION

In hydraulic fluid power systems, power is transmitted and controlled thru a liquid under pressure within an enclosed circuit. Pumps are components which convert rotary mechanical power into fluid power.

With very few exceptions, all fluid power pumps are of the positive displacement type. That is, they have internal sealing means which makes them capable of maintaining a relatively constant ratio between rotational speed and fluid flow over wide pressure ranges. They generally utilize gears, vanes, or pistons. Non-positive displacement pumps, such as centrifugal or turbine types, are seldom associated with fluid power systems.

Pumps are available either as "fixed" or "variable" displacement types. Fixed displacement pumps have pre-selected internal geometries which maintain a constant volume of liquid passing thru the pump per revolution of the pump's shaft. Variable displacement pumps have means for changing the internal geometries so that the volume of liquid passing thru the pump per revolution of the pump's shaft can be changed.

## 1. SCOPE

To include basic methods of test, and methods for presenting the following performance data for rotary positive displacement hydraulic fluid power pumps used in industrial, mobile, and marine applications:

1.1 Pumps

- 1.1.1 Volumetric displacement
- 1.1.2 Output flow
- 1.1.3 Power input
- 1.1.4 Overall efficiency
- 1.1.5 Fluid inlet pressure requirements
- 1.1.6 Volumetric efficiency
- 1.1.7 Mechanical efficiency

This recommended standard also applies to variable displacement pumps when tested under fixed displacement conditions.

In addition to the basic requirements of this recommended standard, other performance information may be necessary to accommodate individual application requirements.

1.2 Excludes pumps which contain integral valving. (?)

1.3 Method of test applies only to the laboratory, not the production line or field. ([illegible] January, 1980)

2. PURPOSE

To provide a uniform and accurate means for determining and expressing pump performance capabilities in a standard form; to guide the establishment of meaningful ratings; and to aid in accomplishing optimum component application.

3. TERMS

(For definition of terms not herein defined, see Reference No. 1)

3.1 Test Parameter: Any one of several physical quantities which are used to assess the performance of a pump but which are controlled at predetermined values throughout the course of a test. Synonym: Independent Variable, Controlled Variable.

3.2 Target Value: A predetermined value for a particular Test Parameter. The test procedure requires the setting in of the Test Parameters at values which are very near the predetermined values.

3.3 Observation: A record of all measured data, both dependent and independent variables, at any one combination of Parameter Values (Target Values).

3.4 Base Operating Condition: A specific operating point during which time all Test Parameters are set to their rated values as recommended by the pump's manufacturer.

4. GRAPHIC SYMBOLS

Graphic symbols used herein are in accordance with References No. 2, 3, and 4. Where References No. 3 and 4 are not in agreement with No. 2, Reference No. 2 governs.

## 5. LITERAL SYMBOLS

### 5.1 Physical Quantity Symbols

| Symbol Steady State | Symbol Transient | Meaning | US Units of Measure | SI Units of Measure |
|---|---|---|---|---|
| Q | q | Flow | Gallons per minute | Liter per minute |
| H | h | Efficiency | percent | percent |
| T | t | Torque | lbs-in | newton-meter |
| P | p | Pressure | PSI | bar |
| N | n | Rotational Speed | RPM | RPM |
| W | w | Power | Horsepower | Kilowatt |
| D | d | Displacement | $in^3$/rev | cc per rev |
| [illegible] | θ | Temperature | °F | °C |

### 5.2 Identifier Subscript Symbols

| Symbol | Meaning |
|---|---|
| i | Ideal, based on design info rather than test data |
| I | Input |
| b | At base Conditions |
| T | Total or Overall |
| O | Output |
| V | Volumetric  Used with efficiencies only |
| M | Mechanical |
| L | Leakage or loss, depending upon associated Quantity Symbol |
| a | Actual, based on test data as opposed to ideal |
| p | Pump |
| D | Differential  Used for pressure only |
| A | Average |
| e | Effective |

## 6. UNITS

6.1 The International System of Units (SI) is used in accordance with Reference No. 5.

6.2 Approximate conversions to "customary US" units are given for information purposes. These appear in parentheses after their SI counterpart, or separate, as in the case of formulas and graphs. Conversion is based upon the "total implied precision" principle.

6.3 Use the SI units on all graphs and data. (The use of customary US equivalents is optional.)

7. GENERAL PROCEDURES

7.1 Pumps

7.1.1 Select and set up all test apparatus per section 8.

7.1.2 Run all tests per section 10.

7.1.3 Using data from section 10, make calculations per section 11.

7.1.4 Using data from section 10 and calculations from section 11, present data per clauses 12.1 and 12.2.

8. TEST EQUIPMENT SELECTION AND GENERAL SET-UP

8.1 For the Power Conversion Tests, set up the circuit as in Figure 1.

8.2 Fluid

8.2.1 Select a fluid:

8.2.1.1 Which is Newtonian, that is, one that does not contain polymeric materials used as thickeners or viscosity index improvers.

8.2.1.2 Which has viscosity characteristics which are within the limits shown in Table 1 or Table 2.

TABLE 1

US UNITS

| Viscosity must be between these limits | | SAE Grade | MIL-L-2104 Grade | Recommendation on Usage |
|---|---|---|---|---|
| At 104°F | At 212°F | | | |
| 160 and 240 SUS | 46 and 51 SUS | 10 | 10 | Preferred |
| 240 and 460 SUS | 51 and 58 SUS | 20 | | Not Preferred |
| 460 and 725 SUS | 48 and 69 SUS | 30 | 30 | Not Preferred |
| 725 and 1050 SUS | 69 and 85 SUS | 40 | 40 | Not Preferred |
| 1050 and 1650 SUS | 85 and 110 SUS | 50 | 50 | Not Preferred |

TABLE 2

ISO UNITS

| Viscosity in CST mut be between these limits | | SAE Grade | MIL-L-2104 Grade | Recommendation on Usage |
|---|---|---|---|---|
| At 40°C | At 100°C | | | |
| 34 - 51 | 6.0 - 7.6 | 10 | 10 | Preferred |
| 51 - 99 | 7.6 - 9.6 | 20 | N/A | Non Preferred |
| 99 - 156 | 9.6 - 12.7 | 30 | 30 | Non Preferred |
| 156 - 226 | 12.7 - 16.8 | 40 | 40 | Non Preferred |
| 226 - 356 | 16.8 - 22.7 | 50 | 50 | Non Preferred |

8.2.1.3 Which is "Not Preferred" only when the pump's Manufacturer declares that the preferred viscosities are too low for the safety of the pump.

8.2.2 Verify the viscosity by measuring it in accordance with Reference No. 8.

8.2.3 Filtration: The position, number and specific description of filters used in the test circuit shall provide a standard of filtration approved by the pump manufacturer and shall be stated. (27 March, 1979)

8.3 Working Instruments

8.3.1 Select Working Instruments which meet the requirements of the applicable annexes to this standard (Note: NFPA/T2.12 and ISO/TC-131/SC-8/WG-3 are developing these annexes).

8.4 Pressure Taps

8.4.1 Select a pressure tap which can be evaluated in accordance with the applicable Annexes to this standard.

8.4.2 Install the pressure tap in locations which agree with Figure 1.

8.5 Size and select all other test equipment to be compatible with the applicable limits entered on the Designated Information Sheet.

8.6 Install necessary safety devices to protect both equipment and personnel.

8.7 Use plumbing and circuit construction techniques to ensure that no entrained air enters the pump inlet port.

8.7.1 Use inlet plumbing which is the same size as that which the pump has.

8.7.2 There can be no changes in inlet plumbing size within 10 inlet pipe inside diameters.

9. PRE-TEST DATA

9.1 Power Conversion Test

9.1.1 Using fluid and pump manufacturers' information, determine items 1 through 8B on the Designated Information Sheet.

9.1.2 Measure the viscosity of the fluid in accordance with Reference No. 8; record on 8C of the Designated Information Sheet.

9.1.3 Determine the viscosity index in accordance with Reference 7; record on 8D of the Designated Information Sheet.

9.1.4 Determine the Target Values using both pump manufacturer's information and the following selection criteria:

9.1.4.1 For variable displacement pumps, use 100%, 75%, 50% and 25% of maximum geometric displacement. Enter the displacement values on Line 9A of the Designated Information Sheet. For fixed displacement pumps, use 100% only.

9.1.4.2 For shaft speeds, use 100%, 80%, 60%, 40% and 20% of rated speed. Enter these speed values on Line 9B of the Designated Information Sheet.

9.1.4.3 For inlet pressures, use the manufacturer's recommended minimum. Enter this pressure value on Line 9C of the Designated Information Sheet.

9.1.4.4 For outlet pressures, use 100%, 80%, 60%, 40%, 20% of base pressure and minimum output pressure. Minimum output pressure must be less than 10% of rated pressure. Enter these pressure values on Line 9D of the Designated Information Sheet.

9.1.4.5 Using the standard viscosity chart of the fluid selected in clause 8.2.1.2, determine the upper and lower target values for temperature so that the two Target Viscosities meet the requirements as given on the applicable line below:

TABLE 3

| SAE Grade of Fluid | MIL-L-2104 Grade of Fluid | Low Temperature Target Viscosity in CST (SUS) | High Temperature Target Viscosity in CST (SUS) |
|---|---|---|---|
| 10 | 10 | 27.4 (130) | 9.9 (59) |
| 20 | N/A | | |
| 30 | 30 | 70.1 (325) | 18.0 (90) |
| 40 | 40 | 101.4 (470) | 25.0 (120) |
| 50 | 50 | [illegible] (700) | 33.9 (160) |

A. Enter both resulting temperatures on Line 9E of the Designated Information Sheet as the two Target [illegible] for the Power Conversion Test.

B. [illegible] applicable Target Viscosities on [illegible] the Designated Information Sheet.

9.1.6 Estimate the Maximum Expected Values of the Test Variables using the [illegible] (Note. The formulas are only estimates [illegible] equipment, they do not assure that actual [illegible] will be achieved):

9.1.5.1 For Maximum Expected Outlet Flow, use

$Q_{max}$ [illegible] Displacement) × (Rated Speed) / 231 GPM

[illegible] Designated [illegible]

9.1.5.2 For input Torque, use

$$T_{max} = \frac{1.4 \times (\text{Rated Pressure}) \times (\text{Design Displacement})}{2\pi} \text{ LB-IN}$$

Enter this value on Line 10B of the Designated Information Sheet.

9.1.5.3 For Case Drain Flow, use 20% of Maximum Expected outlet flow. Enter this value on Line 10C of the Designated Information Sheet.

9.1.5.4 For Input Power, use

$$W_{max} = \frac{(\text{Rated Speed}) \times T_{max}}{63024} \text{ HP}$$

Enter this value on Line 10D of the Designated Information Sheet.

9.2 Evaluation of Measurement Error

9.2.1 Evaluate the Measurement Error in accordance with the applicable Annexes of this Standard (Note: NFPA/T2.12 and ISO/TC-131/SC-8/WG-3 are preparing these annexes). Enter on Desig. Info. Sheet.

9.2.2 Using Table 4:

9.2.2.1 Select a Measurement Accuracy Class for each measured variable.

9.2.2.2 Using the "Basis/Units" column in Table 4 and the specific conditions of this test, determine the Maximum Allowed Error in the units of measure as follows:

A. Shaft Speed MAE =

$$\frac{(\text{Maximum Test Speed}) \times (\%\text{ From Table 4})}{100}$$

B. Inlet Pressure Below Atmosphere MAE =
Selected Value from Table 4

C. Inlet Pressure Below Atmosphere or up to 1 bar above Atmosphere MAE =
Selected value from Table 4

D. Outlet Pressure MAE =

$$\frac{(\text{Maximum Test Pressure}) \times (\%\text{ From Table 4})}{100}$$

E. Inlet Temperature MAE =
Selected Value from Table 4

F. Outlet Flow MAE =

$$\frac{(\text{Maximum Test Flow}) \times (\%\text{ From Table 4})}{100}$$

G. Input Torque MAE =

$$\frac{(\text{Maximum Test Torque}) \times (\%\text{ From Table 4})}{100}$$

H. Case Drain Flow MAE =

$$\frac{(\text{Maximum Test Case Drain Flow}) \times (\%\text{ From Table 4})}{100}$$

9.2.2.3 Enter the above values on the corresponding lines of section 11 of the Designated Information Sheet under the column headed "Max Allowed Error".

Please Take Notice: When Maximum Allowable Error is evaluated correctly, the values are in the units of measure, not percentages.

9.2.3 Compare the Maximum Allowable Errors from 9.2.2 to the Actual Measurement Error from 9.2.1. If the Actual exceeds the Allowable, then a different Class of Accuracy must be selected, or a different measurement method must be employed.

TABLE 4

MEASUREMENT ACCURACY REQUIREMENTS FOR POWER CONVERSION TESTING OF A HYDRAULIC PUMP

(19 September, 1979)

| Variable | Maximum Allowed Error For The Given Class of Measurement* A | B | C | Basis/Units |
|---|---|---|---|---|
| Shaft Speed | ± 0.5 | ± 1.0 | ± 2.0 | Percent of Maximum Measured Value |
| Inlet Pressure When it is Below Atmosphere of up to 1 bar above Atomsphere | ± 1.5 | ± 3.0 | ± 6.0 | Kilopascal |
| Inlet Pressure above 1 bar | ± 0.8 | ± 1.5 | ± 3.0 | Percent of Maximum Measured Inlet Pressure |
| Outlet Pressure | ± .8 | ± 1.5 | ± 3.0 | Percent of Maximum Measured Outlet Pressure |
| Inlet Temperatur. | ± .5 | ± 1 | ± 2 | Degrees C |
| Outlet Flow | ± 0.8 | ± 1.5 | ± 3.0 | Percent of Maximum Measured Outlet Flow |
| Input Torque | ± .8 | ± 1.5 | ± 3 | Percent of Maximum Measured Input Torque |
| Case Drain Flow | ± 1.0 | ± 2.0 | ± 4.0 | Percent of Maximum Measured Case Drain Flow |

* These values represent the maximum allowed errors in the final data (not just the instrument) when the errors are evaluated in accordance with the applicable annexes of this standard (Note: These annexes are being prepared by NFPA/T2.12 and ISO/TC-131/SC-8/WG-3).

DESIGNATED INFORMATION SHEET

HYDRAULIC FLUID POWER PUMP TESTS NFPA 13.9.17

1. Manufacturer: ____
2. Model: ____
3. Serial No.: ____
4. Pumping Principle: ____
5. Rated Pressure: ____
6. Rated Speed: ____
7. Design Displacement: ____
8. Fluid: ____
   A. Manufacturer: ____
   B. Type: ____
   C. Viscosity at 100°F: ____
   D. Viscosity Index: ____
   E. Additives: ____
   F. Specific Gravity: ____
   G. Bulk Modulus: ____
   H. Temp Coef of Expansion: ____
9. Target Values - Power Conversion Test
   A. Displacements: 100% = ____, 75% = ____, %50 = ____, 25% = ____
   B. Shaft Speeds: 100% = ____, 80% = ____, 60% = ____ 40% = ____, 20%= ____
   C. Inlet Pressures: ____
   D. Outlet Pressures: 100% = ____ 80% = ____, 60% ____
      40% = ____, 20% = ____, Min = ____ < 10% Rated Pressure
   E. Inlet Fluid Temperatures: ____
   F. Viscosities: ____
   G. Directions of Rotation: ____
10. Maximum Expected Values of the Test Variables - Power Conversion Test
   A. Outlet Flow: ____
   B. Input Torque: ____
   C. Case Drain Flow: ____
   D. Input Power: ____
11. Error Evaluations - Power Conversion Test

| Parameter | Measurement Class | Max. Allowed Measurement Error (From Table 4) | Actual Measurement Error (From Cl. 9.2.1 |
|---|---|---|---|
| A. Shaft Speed | ____ | ____ | ____ |
| B. Inlet Pressure (Low) | ____ | ____ | ____ |
| C. Inlet Pressure (High) | ____ | ____ | ____ |
| D. Outlet Pressure | ____ | ____ | ____ |
| E. Inlet Temperature | ____ | ____ | ____ |
| F. Outlet Flow | ____ | ____ | ____ |
| G. Input Torque | ____ | ____ | ____ |
| H. Case Drain Flow | ____ | ____ | ____ |

12. Total Number of Observations: ____
13. Testing Agency: ____

## 10. PUMP TEST PROCEDURES

10.1 Install the test pump in the test rig shown in Figure 1.

10.2 Break-in the pump in accordance with manufacturer's recommendations.

10.3 Power Conversion Test

10.3.1 Iterate parameters, ie, speed, inlet pressure, outlet pressure, inlet temperature and pump displacement through all applicable Target Values as recorded on the Designated Information Sheet and in all applicable combinations.

10.3.2 Control the individual Target Values within the limits required in Table 5 (Note: for variable displacement pumps it is recommended that displacement be the slowest changing parameter in order to minimize the problem of returning to a given Target Value after changing displacement and further, it is recommended that the stroking control be locked into a position for a given Target Value).

10.3.3 Record data per Chart 2 for all individual combinations of Target Values.

10.3.3.1 Do not record Target Values, instead record their corresponding actual measured values of the Parameters.

10.3.3.1.1 For pressure Target Values, be sure to set the outlet gauge pressure to a value that puts the pump differential pressure to the Target Value. This will depend upon the inlet pressure at each observation.

10.3.3.2 Take readings only after all parameters and test variables have stabilized within the limits of Table 5 for at least 5 seconds.

TABLE 5 - PARAMETER REGULATION REQUIREMENTS
HYDRAULIC FLUID POWER PUMP TESTS

| | PARAMETER CONTROL |
|---|---|
| Parameter Name | Control the Parameter within the following tolerances |
| Shaft Speed | ± 0.5% of Rated Speed |
| Inlet Pressure Below Atmospheric | ± 0.25 in Hg |
| Inlet Pressure Above Atmospheric | ± 1% of Maximum Measured Inlet Pressure |
| Inlet Temperature | ± 1.0°C (± 2°F) |
| Outlet Pressure | ± 1% of Maximum measured Outlet Pressure |

CHART - 2 POWER CONVERSION DATA
HYDRAULIC FLUID POWER PUMP TEST
POWER CONVERSION TEST

Date__________
Technician__________

| PUMP DISPLACEMENT IN CC/REV (CU-IN/REV) | INLET TEMP IN °C (°F) | SHAFT SPEED IN RPM | INLET PRESSURE IN BAR (PSIG) | OUTLET PRESSURE IN BAR (PSIG) | INPUT TORQUE IN N-M (IN-LB) | OUTLET FLOW IN L/M (GPM) | CASE DRAIN FLOW IN L/M (GPM | |
|---|---|---|---|---|---|---|---|---|
| D | $\theta_I$ | $N_I$ | $P_I$ | $P_O$ | $T_I$ | $Q_O$ | $Q_L$ | |
| | | | | | | | | |

## 11. PUMP CALCULATIONS

11.1 When the optional flowmeter location downstream of the load valve is used (see figure 1), flow data may have to be corrected to the pump outlet using the following formula:

$$Q_{oe} = Q_F \left[ 1 - \frac{(P_O - P_F)}{K_T} + \gamma\,(\theta_O - \theta_F) \right],$$

Explanation of symbols:

$Q_{oe}$ is the effective flow at the high pressure outlet port.

$Q_F$ is the flow as measured in the optional location.

$P_O$ is the measured outlet pressure.

$P_F$ is the inlet pressure to the flowmeter.

$K_T$ is the isothermal secant bulk modulus as supplied by the fluid manufacturer.

$\gamma$ is the cubic coefficient of thermal expansion as supplied by the fluid manufacturer.

The correction formula must be applied if, when the difference between $Q_{oe}$ and $Q_F$ is added to the Actual Measurement Error, the result exceeds the Maximum Allowable Error. If the Maximum is not exceeded, then the correction is not necessary then:

$$Q_{oe} = Q_F$$

11.2 In order to compensate for the inevitable fact that Target Values cannot be perfectly acquired during the test and further, to compensate for the graphical irregularities which accompany imperfect target acquisition, it is permissible to adjust the torque and flow data to values that would have existed had target acquisition been perfect. tne following formulas apply as first approximations:

$$Q_{Adj} = Q_{oe} \times \frac{N_{Target}}{N_{Actual}}$$

which applies only if the actual speed differs from the Target Speed by no more than 10% of Maximum Test Speed, and

$$T_{Adj} = T_{oe} \times \frac{P_{Target}}{P_{Actual}}$$

which applies only if the actual pressure differs from the Target pressure by no more than 5% of the maximum test pressure.

11.3 Calculate the pump input power:

$W_I$ (Watts) = 0.105 $T_I$(n-m) x $N_I$(rpm)

$W_I$ (HP) = $T_I$(in-lb) x $N_I$(rpm)/63024

11.4 Calculate pump output power:

$W_o$ (Watts) = 1.67 x $[P_o - P_I]$(bar) x $Q_{oe}$(L/Min)

$W_o$ (HP) = $[P_o - P_I]$(psi) x $Q_{oe}$(gpm)/1714

11.5 Calculate overall efficiency

$$H_T = \frac{W_o}{W_I}$$

11.6 Determine the Actual Displacement

11.6.1 Separate Power Conversion Test data by displacement and temperature, that is, so that each individual displacement-temperature combination forms a single block of data. For each of those blocks, carry out the following three steps:

11.6.1.1 Calculate the Simple Displacement:

Simple Displacement (cc/rev) =

1000 x $Q_{oe}$(L/Min)/$N_I$(rpm)

Simple Displacement (cu-in/rev) =

231 x $Q_{oe}$(gpm/$N_I$(rpm)

for all observations in each of the data blocks formed in 11.6.1.

11.6.1.2 Scan all data in each block and select the maximum value of the Simple Displacement as the Actual Displacement:

$D_a$ = Max [Simple Displacement]

11.6.1.3 Repeat 11.6.1.1 and 11.6.1.2 for each temperature-displacement data block

11.7 Determine the Volumeteric Efficiency:

11.7.1 For each displacement-temperature combination, calculate the Ideal Flow using the displacement found in 11.6.1.2:

$Q_{oi}$(L/Min) = $D_a$(cc/rev) x $N_I$(rpm)/1000

$Q_{oi}$(gpm) = $D_a$(cu-in/rev) x $N_I$(rpm)/1000

for each observation.

11.7.2 Calculate the Volumetric Efficiency:

$$H_V = \frac{Q_{oe}}{Q_{oi}}$$

11.7.3 Determine the volumetric efficiency at the base operating condition:

$$H_{Vb} = \frac{Q_{oeb}}{Q_{oib}}$$

where $Q_{oeb}$ is the effective output flow at base conditions and $Q_{oib}$ is Ideal Flow calculated using base speed.

11.7.4 Determine the volumetric efficiency at the base operating condition:

$$H_{Vb} = \frac{Q_{oab}}{Q_{oib}}$$

where $Q_{oab}$ is the actual flow when the pump was operated under the condition of rated speed, rated temperature, maximum displacement, rated inlet pressure and rated outlet pressure; $Q_{oib}$ is the ideal flow at base condition which was found in 11.7.1 using rated speed for $N_I$.

11.8 Determine the Mechanical Efficiency:

11.8.1 For each displacement setting, calculate the Ideal Input Torque using the displacement as determined in 11.6.3:

$$T_{Ii}(\text{n-m}) = D_a(\text{cc/rev}) \times [P_O - P_I](\text{bar})/2000\pi$$

$$TI_i(\text{in-lb}) = D_a(\text{cu-in/rev}) \times [P_O - P_I](\text{psi})/2\pi$$

where $P_O$ and $P_I$ are measured values taken from the Power Conversion Test and $P_I$ is a negative value when the inlet pressure is below atmospheric.

11.8.2 Calculate the Mechanical Efficiency:

$$H_M = \frac{T_{Ii}}{T_{Ia}}$$

11.8.3 Determine the Mechanical Efficiency at the base operating condition:

$$H_M = \frac{T_{Iib}}{T_{Iab}}$$

where $T_{Iab}$ is the actual torque measured when the pump was operated under the condition of rated speed, rated temperature, maximum displacement, rated inlet pressure and rated outlet pressure; $T_{Iib}$ is the ideal torque which was found in 11.8.1 using rated values for $P_O$ and $P_I$.

## 12. TEST DATA PRESENTATION

When describing pump performance in accordance with this standard, the following data shall be provided.

12.1 Provide all information contained on the Designated Information Sheet.

12.2 Provide all test data results as described in 12.2.1 and 12.2.2

12.2.1 For each displacement setting, plot graphically (see figure 2) pump performance versus pump pressure differential ($P_O - P_I$) at a constant pump speed ($N_I$).

12.2.1.1 Overall efficiency ($H_T$) versus pressure differential ($P_O - P_I$) with test temperature ($\theta$) as a parameter.

12.2.1.2 Flow output ($Q_O$) versus pressure differential ($P_O - P_I$) with test temperature ($\theta$) as a parameter.

12.2.1.3 Horsepower input ($W_I$) versus pressure differential ($P_O - P_I$) with test temperature ($\theta$) as a parameter.

12.2.1.4 Repeat 12.2.1 for each displacement setting and pump speed combination.

12.2.2 For each displacement setting, plot graphically (see figure 3) pump performance versus pump speed ($N_I$) at a constant test temperature ($\theta$)

12.2.2.1 Flow output ($Q_O$) versus pump speed ($N_I$) with pressure differential ($P_O - P_I$) as a parameter.

12.2.2.2 Overall efficiency ($H_T$) versus pump speed ($N_I$) with pressure differential ($P_O - P_I$) as a parameter.

12.2.2.3 Horsepower input ($W_I$) versus pump speed ($N_I$) with pressure differential ($P_O - P_I$) as a parameter.

12.2.2.4 Repeat 12.2.2 for each displacement setting and test temperature combination.

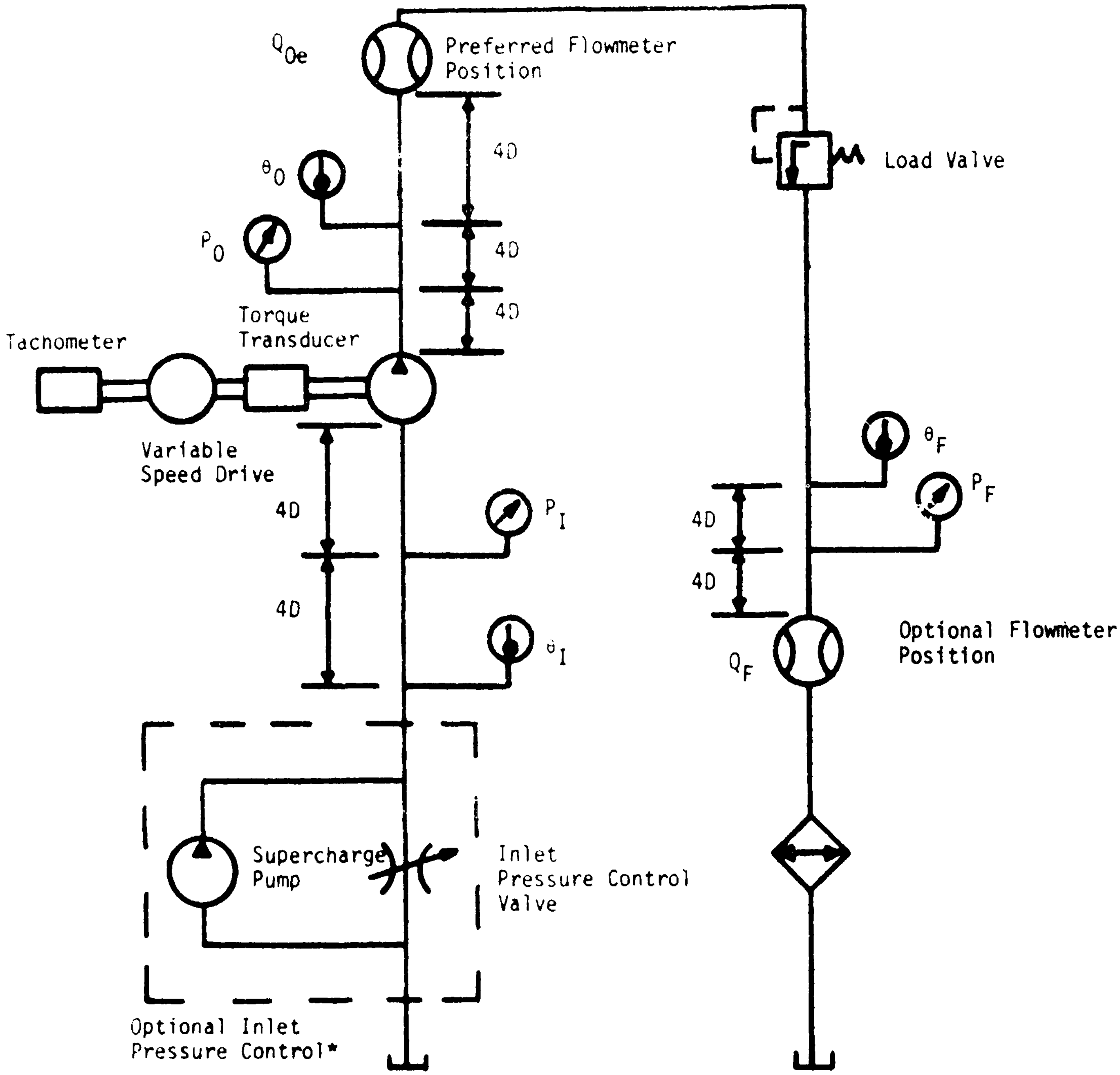
12.3 Graphing of several variables on one set of axes is allowed.

14. IDENTIFICATION

The use of the following statement in catalogues and sales literature prepared by those electing to comply with this voluntary standard is strongly recommended:

14.1 "Performance data obtained and presented per NFPA Recommended Standard T3.9.17-19XX".

FIGURE 1




* If positive inlet pressures are required, the supercharge pump can be used. If very low inlet pressures are required, only the load valve may be necessary.

Note 1: See clause 8.2.3 for filtration requirements

Note 2: When the Optional Flowmeter position is used, it may be necessary to correct for differences in pressure between the preferred and optional positions. See Clause 11.1 for specific procedures and criteria.

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